Cornell University

ANNOUNCEMENTS

College of Engineering

Courses and Curricula

1965–66

FURTHER INFORMATION

UNDERGRADUATES:

All prospective engineering students should write for a copy of the *Announcement of General Information,* which describes the University community in greater detail. *Engineering at Cornell,* an illustrated Announcement prepared especially for pre-college students, should also be obtained, for it describes the many career opportunities in engineering today, and additionally the Cornell campus environment. Both of these Announcements may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York.

GRADUATES:

The *Announcement of the Graduate School* should be consulted for additional information regarding admission, financial assistance, and degree requirements. It may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York.

A brochure, *Graduate Engineering at Cornell University,* describes in considerable detail many of the activities at the graduate level. It may be obtained by writing to the Office of the Dean of Engineering, Cornell University, Ithaca, New York.

Cornell University

College of Engineering

Courses and Curricula

1965–66

Academic Calendar

	1965–66	1966–67
Freshman Orientation	S, Sept. 18	S, Sept. 17
Registration, new students	M, Sept. 20	M, Sept. 19
Registration, old students	T, Sept. 21	T, Sept. 20
Instruction begins, 1 p.m.	W, Sept. 22	W, Sept. 21
Midterm grades due	W, Nov. 10	W, Nov. 9
Thanksgiving recess:		
Instruction suspended, 12:50 p.m.	W, Nov. 24	W, Nov. 23
Instruction resumed, 8 a.m.	M, Nov. 29	M, Nov. 28
Christmas recess:		
Instruction suspended, 12:50 p.m. (10 p.m. in 1966)	S, Dec. 18	W, Dec. 21
Instruction resumed, 8 a.m.	M, Jan. 3	Th, Jan. 5
First-term instruction ends	S, Jan. 22	S, Jan. 21
Registration, old students	M, Jan. 24	M, Jan. 23
Examinations begin	T, Jan. 25	T, Jan. 24
Examinations end	W, Feb. 2	W, Feb. 1
Midyear recess	Th, Feb. 3	Th, Feb. 2
Midyear recess	F, Feb. 4	F, Feb. 3
Registration, new students	S, Feb. 5	S, Feb. 4
Second term instruction begins, 8 a.m.	M, Feb. 7	M, Feb. 6
Midterm grades due	S, Mar. 26	S, Mar. 25
Spring recess:		
Instruction suspended, 12:50 p.m.	S, Mar. 26	S, Mar. 25
Instruction resumed, 8 a.m.	M, Apr. 4	M, Apr. 3
Second-term instruction ends, 12:50 p.m.	S, May 28	S, May 27
Final examinations begin	M, May 30	M, May 29
Final examinations end	T, June 7	T, June 6
Commencement Day	M, June 13	M, June 12

The dates shown in the Academic Calendar are tentative.

CORNELL UNIVERSITY ANNOUNCEMENTS

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Contents

Cornell University

ENGINEERING AT CORNELL

In engineering today, one factor is constant: change. Change is so swift that today's engineering student must be offered a dynamically flexible curriculum which will match his education with the engineering profession's continually changing needs. In its long and distinguished history, the College of Engineering at Cornell has consistently been a leader in the pioneering of engineering programs to meet such needs.

When the University was founded more than one hundred years ago, engineering became an integral part of the range of studies undertaken. At that time Cornell was considered a radical experiment — radical in its assumption that such studies as engineering and agriculture could be developed along with liberal arts programs, and that all could profit from such a close association. The founder and first major benefactor, Ezra Cornell, saw the need for an educational institution that would blend the best of traditional, classical studies with programs that could greatly aid in the total development of the pioneering nation. Cornell, himself, did considerable pioneering work in aiding Samuel F. B. Morse by laying the first telegraph line between Baltimore and Washington, and later he became a major stockholder in the Western Union Telegraph Company.

Cornell's motto, "I would found an institution where any person can find instruction in any study," represented the beginnings of what we know today as the true university concept in higher education. In addition to the College of Engineering, Cornell has six other divisions to which secondary-school students may be admitted — Agriculture, Architecture, Arts and Sciences, Home Economics, Hotel Administration, Industrial and Labor Relations — as well as graduate divisions, such as those in law, veterinary medicine, business and public administration, nutrition, nursing, and medicine. All but the latter two are in Ithaca, New York, on a campus that is generally regarded as one of the most beautiful in America. The School of Nursing and the Medical College are in New York City.

Engineering students, both graduate and undergraduate, not only are a part of a distinguished engineering college but also can draw upon the strengths of the rest of the University for educational development, as well as a rich diet of campus activities. In fact, the College of Engineering at Cornell is one of a handful of major engineering colleges which are also integral parts of great universities. As engineering educational patterns broaden and continue to draw upon the strength of non-technical studies for a part of their professional programs, Cornell's total resources will continue to be of major benefit to engineering students.

Among some of the engineering firsts, Cornell developed the first undergraduate electrical engineering program in the nation, was one of the pioneers in the early development of industrial, mechanical, and engineering physics curricula. In addition, Cornell was the first to award graduate degrees in engineering — the degree of Civil Engineer in 1870 and in 1872, the doctorate in civil engineering. Those degrees were also the first Cornell awarded in any graduate study. In 1885, the first doctorate in electrical engineering was granted. One of the major national scientific fraternities, Sigma Xi, was founded at Cornell in 1886 by Professor Henry Williams of Mechanical Engineering.

Today approximately 2,000 undergraduate engineers are enrolled in the various schools and departments of the College. In addition, about 600 full-time students are working on advanced degrees with aims covering every portion of the broad spectrum of the engineering profession. Two hundred engineering faculty members, complemented by faculties in the University's science and mathematics departments, are able to lend strong support to these students as they seek to explore new areas of technology, and traditional ones too, within the atmosphere of a diverse university.

The accelerating expansion of modern science and technology poses a complex and exciting challenge for engineering education to keep pace with the present, and in fact to lead for the future. Every division of the College is committed to improving its undergraduate programs and to advancing graduate education and research, in order to provide Cornell engineers with the foundation essential for active and rewarding professional careers.

ORGANIZATION OF THE COLLEGE

The College of Engineering offers degree programs at each of the following degree levels: Bachelor of Science, Master of Engineering, Master of Science, and Doctor of Philosophy.

Undergraduate Curricula

An undergraduate student may develop a program of studies in any of the areas or fields listed below. With the exception of the field of agricultural engineering, all freshman and sophomore engineering students are enrolled in the Division of Basic Studies (see page 29) and must complete the requirements of that division before gaining formal admission to any other school or department in the College.

BACHELOR OF SCIENCE DEGREE *

Agricultural Engineering: a program administered jointly by the Colleges of Engineering and Agriculture. Students are enrolled in the College of Agriculture for the first three years, and during the fourth year in the College of Engineering (see page 75).
Chemical Engineering (see page 33).
Civil Engineering (see page 40).
Electrical Engineering (see page 46).
Engineering Physics (see page 51).
Industrial Engineering and Operations Research (see page 59).
Mechanical Engineering (see page 70).
Materials and Metallurgy (see page 65).
College Program: administered by the College Program committee of the College of Engineering. A flexible curriculum developed to encourage unique and well-defined objectives in engineering, not served by one of the aforementioned areas (see page 17).

Graduate Curricula

The College of Engineering offers two distinct Masters' degree programs. One leads to a professional Master's degree, for example, Master of Engineering (Mechanical) and the other to a general degree (Master of Science).

Graduates intending to prepare for professional engineering careers in one of the several engineering fields will generally seek the professional degree. Cornell's undergraduate field programs, coupled with a professional master's degree, offers an integrated curriculum of three years, following completion of the two-year Basic Studies program, to those who seek professional competence.

The Master of Science programs are oriented to students seeking academic or industrial research careers. Both the Master of Science and the Doctor of Philosophy degrees are under the jurisdiction of the University's Graduate School. The professional Masters' degrees are administered by the Engineering Division of the Graduate School unless noted otherwise.

MASTER OF ENGINEERING DEGREES

Aerospace Engineering: administered by the Graduate School of Aerospace Engineering (see page 80).
Agricultural Engineering (see page 79).
Chemical Engineering (see page 38).

* All Bachelor of Science degrees described are granted by the College of Engineering.

Civil Engineering (see page 42).
Electrical Engineering (see page 49).
Engineering Physics (see page 55).
Industrial Engineering (see page 62).
Mechanical Engineering (see page 74).
Metallurgical Engineering (see page 68).
Nuclear Engineering (see page 56).

MASTER OF SCIENCE AND DOCTOR OF PHILOSOPHY DEGREES

For these general degrees, administered by the Graduate School of the University, the faculty is organized into "Fields of Instruction." Most of these Fields coincide with the respective engineering schools or departments. However, in some instances, the faculty is drawn from more than one college at Cornell, and are so indicated in the Fields listed below.

For each Field there is given below an approved list of titles from which candidates for advanced general degress choose major and minor subjects. The numbers 1, 2, 3, 4, 5 have the following meaning:

1, approved as major subject for the Ph.D.
2, approved as major subject for the Master's degree.
3, approved as minor subject when the major is in the same Field.
4, approved as minor subject when the major is in another Field.
5, approved as minor subject for the Master's degree only.

AEROSPACE ENGINEERING

Aerospace Engineering	1, 2, 3, 4
Aerodynamics	4

AGRICULTURAL ENGINEERING (with Agriculture)

Agricultural Engineering	1, 2, 3, 4
Agricultural Structures	1, 3, 4
Electric Power and Processing	1, 3, 4
Power and Machinery	1, 3, 4
Soil and Water Engineering	1, 3, 4

APPLIED MATHEMATICS (with Arts and Sciences)

Applied Mathematics	1, 2, 4

APPLIED PHYSICS (with Arts and Sciences)

Applied Physics	1, 2, 4

ASTRONOMY AND SPACE SCIENCES (with Arts and Sciences)

Astronomy	1, 2, 3, 4
Astrophysics	1, 2, 3, 4
Magnetohydrodynamics	1, 2, 3, 4
Radiophysics	1, 2, 3, 4
Space Sciences (General)	2, 4

CHEMICAL ENGINEERING	
Biochemical Engineering	1, 3
Chemical Engineering, General	1, 2, 3, 4
Chemical Processes and Process Control	1, 3, 4
Materials Engineering	1, 3, 4
Nuclear Process Engineering	1, 3
CIVIL ENGINEERING	
Aerial Photographic Studies	2, 3, 4
Construction Engineering and Administration	1, 2, 3, 4
Geodetic and Photogrammetric Engineering	1, 2, 3, 4
Hydraulics	1, 2, 3, 4
Hydraulic Engineering	1, 2, 3, 4
Sanitary Engineering	1, 2, 3, 4
Sanitary Sciences	3, 4
Soils Engineering	1, 2, 3, 4
Structural Engineering	1, 2, 3, 4
Structural Mechanics	3, 4
Transportation Engineering	1, 2, 3, 4
ELECTRICAL ENGINEERING	
Communication Engineering	1, 2, 3, 4
Control Systems Engineering	1, 2, 3, 4
Electrical Engineering, General	1, 2, 3, 4
Illuminating Engineering	2, 3, 4
Power Engineering	1, 2, 3, 4
INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH	
Applied Statistics and Probability	1, 2, 3, 4
Engineering Administration	2, 4
Industrial Engineering	1, 2, 3, 4
Information Processing	2, 3, 4
Operations Research	1, 2, 4
Systems Analysis and Design	1, 2, 3, 4
MATERIALS SCIENCE AND ENGINEERING	
Materials and Metallurgical Engineering	1, 2, 4
Materials Science	1, 2, 4
MECHANICAL ENGINEERING	
Engineering Drawing	1, 2, 3, 4
Machine Design	1, 2, 3, 4
Materials Processing	1, 2, 3, 4
Thermal Environment	1, 2, 3, 4
Thermal Power	1, 2, 3, 4
Thermal Processes	1, 2, 3, 4
NUCLEAR SCIENCE AND ENGINEERING (with Arts and Sciences)	
Nuclear Engineering	1, 2, 4
Nuclear Science	1, 2

THEORETICAL AND APPLIED MECHANICS

Fluid Mechanics	1, 2, 3, 4
Mechanics of Materials	1, 2, 3, 4
Solid Mechanics	1, 2, 3, 4

WATER RESOURCES (with Agriculture, Arts and Sciences)

Water Resources	4

THE ENGINEERING CAMPUS

Buildings and Laboratories

Ten modern, spacious buildings bring teaching and research together in 14 acres of floor space, and house the finest of equipment. Several of these buildings have been gifts from distinguished Cornell alumni and are described briefly below.

Complementing these new engineering facilities is a new physical sciences building, Clark Hall. Along with the modernization and additional construction under way in physics and chemistry, nearly 20 million dollars will have been spent by the University on strengthening its resources in the physical sciences by 1967. In addition, the construction of a new life sciences building will start shortly.

BARD HALL OF METALLURGICAL ENGINEERING (Gift of Francis N. Bard '04)

Included are areas for processing both metallic and non-metallic materials. A complex of laboratories for structural characterization of materials, with equipment for optical microscopy, electron microscopy, and X-ray diffraction and other methods for investigating the structure of materials is available. Study of radioactive materials and the use of radioactive tracer elements in research are a part of the special facilities within the building.

CARPENTER HALL, ENGINEERING LIBRARY AND ADMINISTRATION (Gift of Walter S. Carpenter '10)

Carpenter Hall houses, in addition to the Engineering Library described on page 00, the administrative offices of the College of Engineering. In addition to the offices of the Dean and his administrative staff, there are areas for admissions, scholarships, and placement services.

GRUMMAN HALL OF AEROSPACE ENGINEERING (Gift of Leroy R. Grumman '16)

A $100,000 shock tube facility which can simulate flight Mach numbers of 20 or greater now makes possible the solution of heating and reentry problems for missiles and satellites. Other laboratory areas in the building are devoted to research in aerodynamics, gas dynamics, and propulsion of aircraft and space vehicles.

HOLLISTER HALL OF CIVIL ENGINEERING (Gift of Spencer T. Olin '21)

Facilities include areas for comprehensive instruction in hydraulics and fluid mechanics, sanitary engineering, and transportation. In addition, there are special areas devoted to filtration column investigations, radioisotope tracer studies, and measurements of environmental radioactivity. Special surveying laboratories and plotting rooms are available for instruction in aerial photogrammetric procedures. A soil mechanics laboratory and a shop and laboratory for constructing models for structural research are also included.

KIMBALL HALL OF MATERIALS PROCESSING

Two unique test beds are available for research and machine testing. They are concrete slabs isolated from the building proper, resting on vibration-absorbing pads above the bedrock. A specially constructed constant temperature (68° F.) room allows for gauge calibration and precise measurement. Undergraduate laboratories in metal cutting, tool forces, chip formation, and power consumption are located in Kimball Hall.

NUCLEAR REACTOR LABORATORY (see page 13)

OLIN HALL OF CHEMICAL ENGINEERING (Gift of the late Franklin W. Olin '86)

Twenty-five small student laboratories are available for small group research. There is also a unit operations laboratory extending through three stories, housing semi-plant-scale equipment for both instruction and research. The Geer Laboratory offers facilities for the study of polymeric materials. The biochemical engineering laboratory contains equipment for research in fermentation and other biochemical processes, and the process control area is equipped with control instruments, recorders and computers.

PHILLIPS HALL OF ELECTRICAL ENGINEERING (Gift of the late Ellis L. Phillips '95)

Laboratories for electronics, communications, illumination, power, servomechanisms, machinery, measurements, and other specialties provide an unusual range of facilities in Phillips Hall. A Network Calculator Laboratory has been equipped with an A.C. power network calculator for student research.

THURSTON HALL OF THEORETICAL AND APPLIED MECHANICS

A dynamic photoelastic laboratory, an applied mechanics laboratory, and a dynamics laboratory are included in Thurston's facilities. In addition, a large test bay is available for macroscopic structural testing of assembled bridges, structural frames, and small, complete buildings.

UPSON HALL OF MECHANICAL ENGINEERING (Gift of Maxwell M. Upson '99)

Laboratories house equipment for studies in heat transfer, fuels, combustion, power, refrigeration, and related fields in mechanical engineering. Other laboratories include those of machine design, vibration research, dynamic analysis, and lubrication.

The Department of Industrial Engineering and Operations Research, also housed in Upson Hall, has facilities for the study of methods engineering, plant layout, and production engineering.

Library Resources

The engineering library, in Carpenter Hall, houses a collection of some 75,000 books and periodicals. The library's pleasant atmosphere is created by the attractive design of the building, the convenient arrangement of its facilities, and its handsome furnishings. In addition to the conventional facilities for reading and research, comfortable chairs for leisurely reading, individual study tables, and a typing and microtext reading room are provided. A staff of professional librarians furnishes reference, bibliographical, reserve, and circulation services.

Among the specialized holdings of the Engineering Library are included a full depository collection of the U.S. Atomic Energy Commission and similar reports from about 20 foreign countries. The Kuichling Library of Sanitary Engineering includes reports of federal, state, and city health agencies and collected papers on water supply works in various cities. For patent research, the library maintains a file of the British patents and a set of the Official Patent Gazette of the U.S. Patent Office (patent abstracts). The library resources of the University total more than 2,600,000 volumes.

A special feature of the library in Carpenter Hall is the Browsing Room. Furnished as a club, this paneled room houses about 1,500 selected books in the fields of the humanities and the social studies. It is designed to provide for students and faculty an inviting collection of cultural reading.

Allied and supporting literature in the basic sciences is to be found in the new physical sciences library in Clark Hall and in the mathematics library.

Historical literature in all the sciences is in the collections of the Olin Graduate and Research Library, which provides study accommodations for 1,000 readers and shelves for two million volumes. A variety of bibliographical, physical and service facilities are provided. Equipment is designed to facilitate use of library materials by students, faculty, and researchers. In the card catalog and bibliography area are the union card catalog and union serials catalog of all books and journals on the Ithaca campus. Also there are the published catalogs of the great libraries of the world, together with the principal indexes, abstracts, and other guides to the literature in the various subject fields. This centralized facility is designed to help researchers keep abreast of new developments in their fields without going from one special collection to another.

A room for the use of microtext material accommodates 24 readers, each with its own microfilm machine and adequate space for note taking. Adjacent is a room in which microfilm and other types of copies of library materials can be made at nominal cost. This eliminates the need for copious note-taking and allows greater use of material that is in great demand.

Another special facility is the map room. The Library has a current collection of about 50,000 maps, storage space for tripling the collection, specially-designed work and consultation facilities, and light-tables for tracing copies of maps.

The Cornell Computing Center

In recognition of the growing impact of computer technology on nearly every area of engineering analysis, a Department of Computer Science has been established on an inter-college basis. The facilities of the Cornell Computing Center, which houses a Control Data 1604 digital computer and various auxiliary equipment, are available for use by students and faculty. In addition to the several courses offered by the Department of Computer Science in the principles and operation of computers, many other engineering courses make active use of these powerful computational tools in class assignments, projects, and research investigation.

Materials Science Center

The Materials Science Center (MSC) at Cornell is an interdisciplinary laboratory created to promote research and graduate student training in all phases of the science of materials. The subjects of study represented in the MSC program are chemistry, electrical engineering, materials engineering, materials science, applied physics, metallurgy, and physics.

Several central facilities have been set up where more specialized apparatus such as crystal-growing furnaces, high-pressure equipment, X-ray and metallography equipment, electron microscopes, etc., are available. In addition to the equipment, expert advice on its use and the interpretation of the results is available. In these central facilities, it is expected that the student will come in contact with students from other disciplines, resulting in a mutually profitable relationship.

The Nuclear Reactor Laboratory

The College of Engineering has in operation a nuclear reactor facility unique among those in educational institutions.

The Laboratory contains: (1) a TRIGA reactor which may be operated steadily at 100kw producing a neutron flux of 1 to 5 x $10^{12}/cm^2$ sec. In addition, the reactor may be pulsed to a peak power of approximately 250 megawatts for the study of phenomena of brief duration. The width of the pulse at half maximum is approximately 40 millisec. Eight beam ports and a thermal column allow flexible use of neutrons and radiation. (2) A "zero power" reactor (critical facility) of versatile design for basic studies of reactor physics. (3) Subcritical assemblies for similar studies. (4) A shielded cell for chemo-nuclear work with up to 10,000 curie gamma sources and other radioactive materials.

Accompanying laboratory space permits work with radioactive materials at low levels. A 3 Mev, 0 to 10 milliampere Cockroft Walton accelerator, for studies of radiation effects and low energy nuclear levels and reactions has recently been added to the facilities of the laboratory.

Center for Radiophysics and Space Research

The facilities of the Center include the lunar surface and electronics laboratory on the Cornell campus, the radio astronomy and ionospheric laboratories close to Ithaca, and the Arecibo Ionospheric Observatory in Puerto Rico. The latter has in operation a 1,000 foot diameter radar-radio telescope, the largest of its kind in the world. It affords unique possibilities for space research. Among topics under current study are:

ASTRONOMY AND ASTROPHYSICS. Astronomical aspects of cosmic rays, gamma-radiation, X-rays, neutrinos; cosmology; experimental studies and theory relating to the surface of the moon and the planets; processes in the interstellar gas; solar system magnetohydrodynamics; stellar statistics; theory of stellar structure, stellar evolution, nuclear processes in stars.

ATMOSPHERIC AND IONOSPHERIC RADIO INVESTIGATIONS. Dynamics of the atmosphere; incoherent electron scattering; study of refraction, scattering, attenuation due to the inhomogeneous nature of the troposphere and ionosphere; theory and observation of propagation of radio waves in ionized media such as the ionosphere.

RADAR AND RADIO ASTRONOMY. Distribution and classification of radio sources; radar studies of the moon and planets; solar radio observations.

SPACE VEHICLE INSTRUMENTATION. Instrumentation relating to lunar exploration; magnetic field measurements; tenuous gas and particle flux measurements.

UNDERGRADUATE DEGREE PROGRAM

Students entering as freshmen in the College of Engineering at Cornell in September, 1965, will be enrolled in new undergraduate degree programs. Under the new curricula, a student will receive a Bachelor's degree following four years of study and an opportunity to earn a professional Master's degree in one additional year as part of an integrated five-year engineering program. Alternatively, after receiving the Bachelor's degree, the student may seek a Master of Science degree.

These new degree programs offer students two distinct paths to the Bachelor's degree. One path will enable a student who enrolls in one of the College's several professional field programs, such as mechanical engineering, to prepare for graduate study or employment in an established engineering field. The other path will accommodate those students with special educational objectives to follow an individualized program including one of the following possibilities: more intensive work in the fundamental engineering sciences, or in one area of a professional field; interdisciplinary programs within the various fields of engineering, or with engineering and other Cornell curricula; more general programs which will place a greater emphasis on liberal studies.

Students intending to engage in the practice of professional engineering will be encouraged to continue their studies for one additional year beyond the Bachelor's degree, and will receive a professional Master's degree. This is an integrated undergraduate-graduate program which accounts for the somewhat shorter period of time required to earn both degrees.

The purposes of the new undergraduate program in Engineering at Cornell are to provide an educational basis which will support the increasing range of activity undertaken by engineers in all forms of human endeavor, and to accommodate the rapid change taking place in all the established fields of engineering.

Cornell's new programs reflect the nationwide trend toward graduate and advanced study in engineering. They provide flexibility for responding to the enormous and changing demands on engineering education and engineering practice. At the same time Cornell will retain one of the features for which it has long been recognized — strong programs leading to practice in the major fields of professional engineering.

THE COMMON STUDIES CORE

One of the goals of the new curricula is to foster the development of a sound education which can be directed toward a wide choice of careers in engineering and applied science. Studies during the junior and senior years, as well as subsequent graduate work in the College, will complement the course work included in the core. Two-thirds of the credit hours in the College's new undergraduate programs are included in this core, with the remainder devoted to the development of a specific educational goal in either one of several Field Programs or the College Program. (Both Field Programs and the College Program are described in the sections which follow.)

All freshmen will take a common program of studies, except for those obtaining advanced placement. Mathematics, physics, chemistry, and English are included in the freshman year. In addition, one introductory engineering course taught by members of the engineering faculty is offered each year. One of these introduces fundamentals of engineering graphics and the role that the design function plays in modern engineering. The other course stresses the functions of modern engineering, the nature of engineering and the interrelationships of several professional fields. Freshmen learn CORC, the Cornell computing language, while enrolled in this latter course, and make subsequent use of it in their mathematics, science, and engineering courses.

Both of these introductory courses encourage close student-faculty association. Advisers drawn from the College's faculty provide another opportunity for students to become more acquainted with the many opportunities open to them in the Cornell programs.

During the sophomore year the core includes further work in mathematics and physics and a liberal studies course in each term for all students. To round out the sophomore year, two engineering science courses are chosen by a student each term. It is intended that these serve as the mechanism linking his work in mathematics and sciences with studies in the upperclass engineering program. There are several engineering sciences which can be selected by the student — among them are mechanics, physical chemistry and materials science, and electrical science. A choice of any two is not intended to limit a student's subsequent choice of program but should help him to focus upon that part of the spectrum of engineering in which he intends to develop his future studies.

After completing the sophomore year, a Cornell engineering student may enroll in one of the several Field Programs or the College Program. In either option, he will continue work in the core by including two additional engineering sciences, twelve credit hours of liberal electives and six credit hours of unspecified electives during his junior and senior years.

FIELD PROGRAMS

Students intending to enter practice in one of the several traditional engineering fields taught by the College will enroll in a Field Program in their junior year. At present, Field Programs are offered in agricultural, chemical, civil, electrical, industrial, and mechanical engineering, plus engineering physics and materials and metallurgy. To prepare for entry to one of these fields, the appropriate engineering science courses would be selected during the sophomore year (see the Common Studies Core, page 15). For example, a student considering electrical engineering might take courses in electrical science and mechanics as his preparatory engineering science courses during the sophomore year.

In any of these several fields, further core studies are continued through required liberal electives, free electives, and additional engineering science electives. Approximately 30 percent of the four-year program is devoted to professional studies of a chosen field.

At the completion of the four-year Field Program, a graduate may be admitted to the College's professional Master's degree program, earning that degree in one additional year. The professional Master's degree program represents the level at which graduates will be prepared to seek *professional* engineering employment. The degree includes advanced work in a field begun formally during the junior year and represents a three-year program of integrated studies particularly suited to the requirements in modern industry.

Individuals seeking careers in research in applied science or in a specialized engineering area, such as sanitary engineering within civil engineering, can apply for the Master of Science or the Ph.D program at the end of the four-year Bachelor's program. Some students may want to undertake graduate or professional study in other fields such as law, business, public administration, or medical research. It will be their decision as to which level of preparation they seek in engineering — the Bachelor of Science or professional Master's before embarking on other studies. The Bachelor of Science degree in a Field Program may be the terminal point in the formal education of some students; however, it is expected that most will seek to continue studies beyond this stage.

THE COLLEGE PROGRAM

The College Program has been established to accommodate those students whose educational objectives require more curricular flexibility than is possible in the Field Programs. Thus, to reach a given objective, a student in the College Program may combine course sequences from two or more engineering fields or combine an engineering course sequence with a sequence from a non-engineering discipline. Many combinations are possible under the program as established and the College Program Committee, which will administer the program, will approve all proposals that combine sequences of courses that it deems logically related to an educational objective having an engineering foundation.

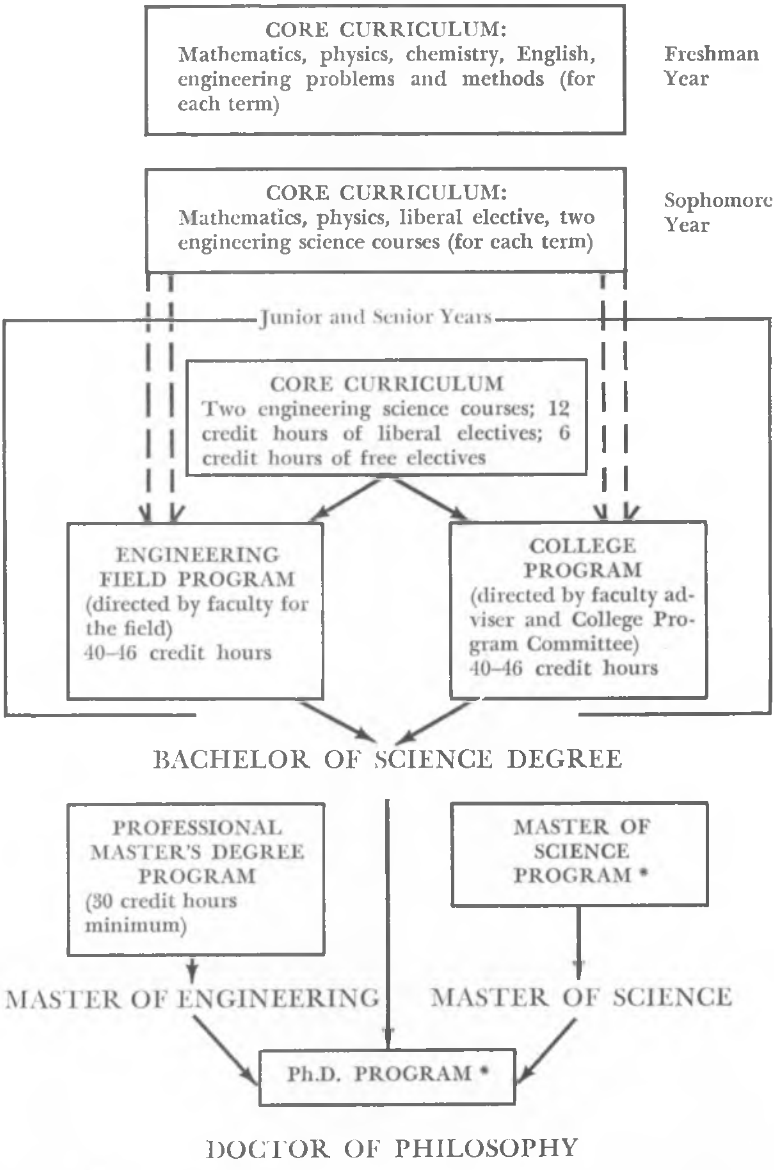
Similar to the Field Programs in that the same core curriculum requirements must be satisfied, the College Program differs from the Field Programs in that the courses to satisfy the 40 to 46 additional credit hours are not specified by the engineering faculty, but are to be suggested by the student when he applies for admission to the College Program. Such admission will normally be at the beginning of the student's junior year but applications to the program will be accepted as early as the second term of the freshman year.

Within these 40 to 46 credit hours, the student is required to have at least a minimum of 12 hours in an engineering major, 8 hours in an engineering minor, and 8 hours in technical electives, with the remaining hours to be satisfied by courses appropriate to the student's objective. The engineering minor may be waived if the objective of the student is best satisfied by a combination of an engineering major and a minor that is in a non-engineering discipline.

Completion of the application form for admission to the program will require a statement of the objective of the student and a term-by-term listing of the courses that are proposed for meeting this objective. It is not expected that the student will compile such a listing on his own, but that after discussing his objective with the chairman of the College Program Committee he will develop his program with the advice of a technical consultant in the field of the proposed major. The technical consultant will be a professor recommended to the student by the chairman of the Committee.

Once admitted to the program, the student's progress will be under the supervision of the College Program Committee. His adviser will be the chairman of the Committee. The Committee is responsible for all the administrative functions normally performed by the faculty of a Field Program.

SUMMARY OF DEGREE REQUIREMENTS FOR B.S., M.ENG., M.S., AND Ph.D.



* Consult the *Announcement of the Graduate School* for detailed requirements for the M.S. and Ph.D. degree programs.

THE INDUSTRIAL COOPERATIVE PROGRAM

During the fourth term, an above-average student who intends to pursue a program in electrical, industrial, or mechanical engineering, or engineering physics, may apply for admission to the Industrial Cooperative Program.

If accepted in that program he will have an opportunity to gain practical experience in his chosen field, which can be of value to him in planning his program and carrying out his studies. In addition, he not only earns a substantial salary during his periods of employment, but also gains about a year in the amount of responsibility he can undertake upon graduation.

By utilizing the summers following his second, third, and fourth years, the student is able to complete the academic requirements for his Bachelor's degree, pursue his work program totaling nearly one year in industry, and still graduate with his class on time. He is on campus with his regular classmates except during the fifth term.

The schedule for the Cooperative Program, beginning after the fourth term, is as follows:

Summer:	Fifth term courses
Fall:	Industry
Spring:	Sixth term courses
Summer:	Industry
Fall:	Seventh term courses
Spring:	Eighth term courses
(Award of B.S. Degree)	
Summer:	Industry

Students who seek a Master's degree are able to begin graduate study in the fall following receipt of the Bachelor's degree, just as in the regular program.

The work program of each participant is arranged to advance his individual interests and aptitudes within the regular activity of the company with which he is affiliated. Because the plan visualizes progression from less demanding assignments through to development, research, and other more advanced responsibilities, it is not feasible for any one student to work in more than one industrial organization. He is therefore admitted to the Program by arrangement with one company and is in their employ throughout the program. Neither the student nor the company, however, is obligated in any sense for employment beyond the completion of the Industrial Cooperative Program.

Among the companies presently participating in the Program are American Electric Power Service Corporation, Anaconda Wire and Cable Company, Cornell Aeronautical Laboratory, The Emerson Electric Manufacturing Company, General Radio Company, Gleason Works, International Business Machines Corporation, and Raytheon Manufacturing Company.

Further information is available from the Industrial Cooperative Program office, 109 Phillips Hall.

ADMISSION

Detailed information concerning the methods and procedures of undergraduate admission is given in the *Announcement of General Information.*

REQUIREMENTS FOR ADMISSION AS AN UNDERGRADUATE

Secondary School Credits

Sixteen units of college preparatory subjects are required. The following fourteen units must be included:

Subject	*Units*
English	4
History	2
One foreign language	2
Algebra (elementary and intermediate)	2
Plane geometry	1
Trigonometry	1/2
Advanced algebra or solid geometry	1/2
Chemistry	1
Physics	1

College Board Tests

The Scholastic Aptitude Test of the College Entrance Examination Board is required of all applicants. All applicants also must take the College Board achievement tests in mathematics and in chemistry or physics. The Level I achievement test in mathematics is required of all applicants and must be taken not later than January of the senior year. The Level II test may be taken, in addition, by applicants who wish placement in advanced sections of the first calculus course. Applicants should take the achievement test in chemistry or physics in May of the junior year, or in December or January of the senior year, provided they have completed one year of study in the subject in the junior year.

Other Factors

Applicants will be admitted to the College of Engineering who in all essential respects have demonstrated a high order of scholastic achievement and who, so far as can be determined, have a well-considered desire to study engineering. They must possess positive characteristics of work and study and the maturity necessary to meet the demands of living successfully in an active and stimulating university environment. Good grades or high College Board scores are in themselves no guarantees of success or even of admission. High motivation and the desire to succeed are equally important.

Advanced Placement

Throught cooperation with the advanced placement program of the College Entrance Examination Board and departmental tests given during the fall orientation period, normally one-fifth of the class is given advanced placement or actual college credit for one or more courses of the freshman year. This makes possible more individual development toward a broader liberal program or advanced technical study in line with the student's own inclination. Superior students, who have achieved advanced placement in mathematics and in either chemistry or physics upon graduation from high school, may find it possible to enroll at the sophomore level if they attend the University summer session preceding September matriculation and take the other science. Students with superior performance in the freshman year are encouraged to enroll in honors sections at the sophomore level.

TRANSFER AND SPECIAL STUDENTS

Students desiring to transfer to the College of Engineering from another Cornell division or from another university or college are invited to communicate with the Director of the Division of Basic Studies, Hollister Hall, if they have the equivalent of two or fewer years of applicable college credit. If it appears that the equivalent of all the courses of the Basic Studies curriculum (pages 31–32) has been successfully completed, prospective students should communicate with the Director of the professional school in which they are interested.

In exceptional cases, individuals who do not wish to become candidates for any of the undergraduate degrees may be admitted to the College of Engineering as special students. Prospective students who cannot meet the entrance requirements or who do not wish to spend the required time to complete the course must have had some engineering training, and must satisfy the prerequisites for the courses they wish to take. Others with a baccalaureate degree wishing to pursue further work at the undergraduate level may also be admitted as special students. In either instance, individuals should write to the director of the professional school to which they want to be admitted as special students.

Applications for admission and general University information may be obtained by writing the Office of Admissions, Edmund Ezra Day Hall.

REQUIREMENTS FOR ADMISSION TO THE GRADUATE DEGREE PROGRAMS

A graduate student holding a baccalaureate or equivalent degree from a college or university of recognized standing may pursue advanced work leading to a graduate degree in engineering. Such a student may enter as a candidate either for the general degrees (M.S. or Ph.D.) or for the professional engineering degrees — Master of Engineering (Aerospace, Agricultural, Chemical, Civil, Electrical, Engineering Physics, Industrial, Mechanical, Metallurgical, or Nuclear).

General Degrees

The M.S. and Ph.D. degrees are available in all fields and subdivisions of the College of Engineering. They are administered by the Graduate School and require work in both major and minor fields of study, as well as the completion of a satisfactory thesis, usually involving individual and original research. A prospective graduate student interested in obtaining an M.S. or Ph.D. degree should consult the *Announcement of the Graduate School* for additional information concerning these degrees and should correspond with the professor supervising the particular field of engineering representing his major interest. Students who do not completely meet the entrance requirements for these degrees may be admitted as provisional candidates or without candidacy according to previous preparation, but they must in all cases hold a baccalaureate or equivalent degree.

Professional Masters' Degrees

Professional degrees at the Master's level are offered in aerospace, agricultural, civil, electrical, industrial, mechanical, metallurgical, and nuclear engineering, and in applied physics. All except the degree in aerospace engineering are administered by the Engineering Division of the Graduate School. The Master of Engineering (Aerospace) degree is granted on the recommendation of the faculty of the Graduate School of Aerospace Engineering; prospective candidates for this degree should apply directly to the Director of the Graduate School of Aerospace Engineering.

These degrees are intended primarily for persons who wish to enhance their ability in the practice of engineering, and not for those who expect to enter engineering teaching or research. The student with a baccalaureate degree in the area of engineering or science deemed appropriate to his proposed field of study may become a candidate for a professional degree.

The professional degrees require a minimum of 30 credit hours of graduate-level work in the principles and practices of the specific field. They do not require the presentation of a thesis based upon research studies; however, they require from three to twelve credit hours of individual work in some aspect of engineering design, including submission of a formal report. Each program also requires completion of a curriculum of related technical courses, differing in content among the several professional degrees. Each curriculum includes some prescribed and some elective courses, with considerable flexibility to permit adaptation to the special needs of the individual student.

The professional degrees are at the fifth-year level of university work and require, in general, one year of additional study beyond a four-year baccalaureate program. Cornell alumni who hold the five-year Bachelor of Engineering degree may — if they have made a sufficiently strong academic record in specified technical courses — be able to complete the requirements for the Master of Engineering degree in one term of fifteen credit hours. Candidates may be admitted to some of the professional programs with minor deficiencies to be made up during their graduate study; in such cases more than two terms of work may be required.

A candidate interested in entering the graduate professional program should write to the director of the division of engineering he plans to enter.

TUITION AND FINANCIAL AID

TUITION AND FEES

Tuition in the College of Engineering is $750 per term. In addition, there is a University General Fee of $150 per term. The latter contributes toward the various services provided by the University, such as the libraries, the clinic and hospital, recreational facilities, and the student center in Willard Straight Hall.

For further information relating to payment of tuition and fees, refunds, application and registration fees, estimates of living expenses, etc., consult the *Announcement of General Information.*

UNDERGRADUATE FINANCIAL AID

Scholarships, loans, and employment are available in substantial amounts to aid students in meeting the cost of their education. Nearly a quarter of a million dollars is awarded annually by the University to engineering freshmen alone. Recently over 65 per cent of all undergraduate engineering students have held scholarships or grants-in-aid, exclusive of loans.

Freshmen seeking financial assistance file a single application with the University Office of Scholarships and Financial Aid. Those who receive scholarships administered by the College of Engineering should deal directly with the Office of Student Personnel of the College of Engineering on any question relating to these awards. Specifically, these are the scholarships awarded to incoming freshmen which they may continue to hold throughout their college course.

Upperclassmen with financial need, who did not receive Cornell awards at the time of entrance, should initiate all applications for financial aid with the Office of Scholarships and Financial Aid, Day Hall. A booklet listing all scholarships and loans available to students is published by that office. Upperclassmen who thus apply for financial assistance will be interviewed by scholarship committees before awards are made, but their applications must originate with the Office of Scholarships and Financial Aid.

GRADUATE FINANCIAL AID

Financial aid to graduate students is available in several forms: fellowships and scholarships, research or teaching assistantships, residence hall assistantships, and loans.

Graduate students whose major subjects are in the various branches of engineering and who wish to be candidates for scholarship or fellowship aid should consult the *Announcement of the Graduate School* and make application to the Dean of the Graduate School. Those who are candidates for the professional degrees should apply to the director of the appropriate field. Information relating to application for the other forms of financial aid mentioned above will also be found in the *Announcement of the Graduate School.*

PRIZES

Cornell University has a considerable number of funds given for the endowment of prizes to be awarded annually. Some of these prizes are open to competition by any students in the University. The publication, *Prize Competitions,* describing the prizes and the nature of the competitions, may be obtained at the Visitor Information Center, Day Hall. Prizes open to competition particularly by students of the College of Engineering are:

THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS PRIZE. The "Student Branch Scholastic Award" of the American Institute of Aeronautics and Astronautics is presented annually to the M.Eng.(Aero.) candidate who attains the best scholastic record for that academic year. The award consists of a certificate and a two-year free technical membership in the Institute.

THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS PRIZE is a badge awarded by the School of Chemical Enginering to a junior in chemical engineering for the best scholastic record at the end of the fourth term.

THE AMERICAN SOCIETY OF TESTING MATERIALS PRIZES, consisting of six one-year memberships in the Society, are awarded to students in the College of Engineering for the highest scholastic average in materials.

THE CHARLES LEE CRANDALL PRIZES, founded in 1916 by alumni of the School of Civil Engineering. The prizes of $200 and $100 are awarded each year by a committee appointed by the Director of the School of Civil Enginering for the best papers written by students in the fifth term or above in that School, on suitable subjects, provided that both the substance and the written form of the papers submitted show real merit. The prizes were established to encourage original research, to stimulate interest in matters of public concern, and to inspire in the students an appreciation of the opportunities which the profession of civil engineering offers them to serve their fellow men as intelligent and public-spirited citizens. Papers must be submitted to the Director of the School of Civil Enginering on or before April 15 of each year.

THE FUERTES MEDALS, established by the late Professor E. A. Fuertes. The endowment provides for two gold medals. One is awarded annually by the faculty to that student of the School of Civil Engineering who is found at the end of the first term of his senior year to have maintained the highest degree of scholarship in the subjects of this course, provided he has been in attendance at the University for at least two years. The other is awarded annually by the faculty to a graduate of the School of Civil Engineering, or the recipient of a graduate degree with major in civil engineering, who has written a meritorious paper upon some engineering subject tending to advance the scientific or practical interests of the profession of the civil engineer. It is desired that papers be presented on or before April 15. If a paper is presented in printed form, it will not be received if it has been printed earlier than the preceding April 15. Neither medal is awarded unless it appears to the faculty of the School of Civil Engineering that there is a candidate of sufficient merit to entitle him to such distinction.

THE FUERTES MEMORIAL PRIZES IN PUBLIC SPEAKING, established in 1912, consist of several prizes totaling at least $200. They are awarded by a committee of seven judges to students in the fifth term or beyond of the Colleges of Architecture and Engineering for proficiency in public speaking.

THE HAMILTON AWARD. A suitably engraved Hamilton watch and letter of commendation is awarded annually to the senior in engineering who has most successfully combined proficiency in his major field of study with achievements, either academic, extracurricular, or a combination of both in the social sciences and humanities.

THE HAROLD RAYMOND NELSON PRIZE IN ENGINEERING PHYSICS, established in 1964 in the amount of $400, is awarded solely on the basis of achievement in the student's senior project. Selection criteria include originality, effort, and effectiveness of written presentation.

SIBLEY PRIZES. Under a gift of Hiram Sibley, made in 1884, the sum of $100 is awarded annually in several prizes to fifth year students in mechanical engineering and electrical engineering, equally distributed, who have received the highest average in the preceding four years.

THE SILENT HOIST AND CRANE COMPANY MATERIALS HANDLING PRIZE, established in 1950 by the Wunsch Foundation, is in an amount approximating $300 and is awarded for the best original paper on the subject of materials handling at the discretion of a College of Engineering faculty committee. This contest is open to undergraduate and graduate students of the College of Engineering.

THE WILLIAM WAYNE KRANTZ AWARD, established by the Class of 1961 in Electrical Engineering in memory of their classmate who died on August 6, 1960, is made to the fifth year student in Electrical Engineering who has demonstrated qualities of perseverance, ambition, courage, and unwavering desire to become an electrical engineer. Award consists of a shingle and enrollment of the winner's name on a plaque in Phillips Hall.

THE J. G. WHITE PRIZES IN SPANISH. Through the generosity of James Gilbert White (Ph.D., Cornell '85), three prizes, established in 1914, each of the value of $100, are offered annually. One of the three, which is awarded to an English-speaking student for proficiency in Spanish, is open to members of the junior and senior classes in the College of Engineering who are candidates for their first degree. No candidate is eligible unless he has completed successfully two terms of work in Spanish at Cornell University.

STUDENT LIFE AT CORNELL

HOUSING

University residence halls, located within convenient distance of academic buildings, libraries, and other campus facilities, provide accommodations for approximately 2,000 undergraduate men. Nearly all freshmen reside in dormitories; upperclassmen may reside either in dormitories, in fraternity houses, or in off-campus rooms or apartments. Dining facilities are provided in several locations throughout the campus.

Housing facilities for undergraduate women, graduate students, and married students are also available. Consult the *Announcement of General Information* for further details.

UNIVERSITY ACTIVITIES

Cornell offers the opportunity of participating in a varied program of extracurricular activities. Something can be found to meet nearly every interest, including student government, athletics, publications, music, dramatics, and various social and cultural organizations.

The intercollegiate athletic program is the largest in the country, with competition in 22 sports. In addition, the various athletic facilities are available for intramural and informal competition.

Throughout the year, there are several opportunities to hear lectures by distinguished visitors to the campus. Concerts and dramatic performances are offered, both by university groups and by outside artists. Art of various forms is on display at the Andrew Dickson White Museum and at the Art Room of Willard Straight Hall.

Cornell students publish a full-scale, daily newspaper, the *Cornell Daily Sun,* a yearbook, and several literary and humor magazines. The campus radio station, WVBR, is operated entirely by students.

There are international and political clubs, service clubs, professional and departmental societies, and clubs devoted to almost anyone's hobby.

Religious Affairs

Although Cornell has been a nonsectarian institution from its founding, it has a center for the coordination and sponsorship of religious activities. A staff of twelve University chaplains represent the major religious denominations. Thus facilities and personnel for religious study, worship, counsel, and fellowship are available. In addition, each Sunday distinguished visiting clergymen from throughout the world conduct interdenominational services in Sage Chapel.

Health Services

Health services and medical care are available at Cornell's Gannett Clinic and Sage Hospital (a fully accredited hospital). Student fees cover treatment and care at the Clinic and Hospital, with up to two weeks of hospitalization per term. Consult the *Announcement of General Information* for details.

Physical Education

All freshmen and sophomores are required to take physical education. The freshman program includes activity in each of six sports, while in the sophomore year students concentrate on one or two sports.

Officer Education

The Army, Navy, and Air Force all offer ROTC programs at Cornell. Participation is voluntary, and successful completion of the program results in a commission in the chosen service. For further information, consult the *Announcement of Officer Education.*

COLLEGE HONORS AND ACTIVITIES

Dean's Honor List

Undergraduate students in the College of Engineering whose weighted average in their studies is 85.00 per cent or better are included annually in an Honor List compiled for the Dean. The honor students comprise approximately the highest tenth of all the students enrolled in the College.

Honor Societies

Engineering students may qualify for membership in local and national honor societies, including Tau Beta Pi, Phi Kappa Phi, Sigma Xi, Pi Tau

Sigma, Chi Epsilon, Rod and Bob-Pyramid, Atmos, Kappa Tau Chi, and Eta Kappa Nu.

Student Publication

The *Cornell Engineer,* a magazine containing articles of professional interest for engineering students and alumni, is published throughout the academic year by undergraduates of the College of Engineering.

Engineering Societies

Many meetings of the American Society of Civil Engineers, American Institute of Industrial Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, Society of Automotive Engineers, and Institute of Electrical and Electronic Engineers are held on campus and are attended by students. The College also maintains active student branches of these societies, as well as of the American Institute of Chemical Engineers, American Society of Agricultural Engineers, and the American Institute of Aeronautics and Astronautics. The Cornell Metallurgical Society was formed in 1949 and is an affiliate of the American Institute of Mining and Metallurgical Engineers. A student branch of the American Nuclear Society was founded in 1959.

Engineering Student Council

The Engineering Student Council, consisting of elected student representatives from each division of the College, plans the annual Engineers' Day program for high school visitors to the campus and represents student viewpoints in campus affairs. Upperclassmen on the Council have participated in an informal tutoring program for freshmen desiring such assistance.

STUDENT PERSONNEL SERVICES

Advising and Counseling

The University provides extensive personnel services and counseling facilities for all students. Among these are the Office of the Dean of Students, the University Health Services, the Reading-Study Center, the Educational-Vocational Guidance Office, Cornell United Religious Work, the University Placement Service, and the Office of Scholarships and Financial Aid.

For planning and scheduling his academic work each engineering student is assigned an adviser. The adviser should usually be the first point of reference in all matters of student counseling, and should always be consulted on questions of curriculum, academic standards, or scholastic performance. In addition, students are free to consult with the

Dean, directors, and other faculty members on any educational or personal matters.

The Office of Student Personnel, 221 Carpenter Hall, is the focal point in the College for the admission of freshman students, the administration of the engineering scholarship funds, the placement of graduating students, and the compilation and maintenance of alumni records. It is a source of information on all personnel services to students, and any student is welcome to consult the Director of the Office on non-academic matters. Special provision is made for questions relating to financial aid and placement.

Placement

The facilities of the University Placement Service are available to all engineering students for summer and permanent employment. The Office of Student Personnel in cooperation with the Placement Service annually arranges interviews between students and prospective employers. Members of the engineering faculty are assigned as placement advisers with whom students may discuss their career objectives, whether for employment or graduate study. Information about companies is available both in the Placement Service and the Office of Student Personnel, and students may discuss specific employment opportunities and the procedures of job placement with the staff of either office.

AREAS OF INSTRUCTION

DIVISION OF BASIC STUDIES

HOLLISTER HALL

Mr. H. G. Smith, Director.

Freshmen in the College of Engineering are enrolled for the first two years of their undergraduate program in the Division of Basic Studies of the College of Engineering. The Division is responsible for admissions to the College at the underclass level, administers a program of courses for freshmen and sophomores, and assigns each engineering underclassman a senior member of the College of Engineering faculty as his adviser.

The freshman year program includes studies in mathematics, physics, chemistry, and English. Through contact with senior engineering staff, both as advisers and in class discussions in engineering problems and methods courses, the student is made more fully aware of the range of opportunities in the engineering profession. Instruction in graphics as a form of technical communication, some features of engineering economy, use of modern digital computing machines, introduction to an attitude of problem solving in which there is no unique answer, and design at an elementary level based on concurrent mathematics and science courses, are features included in these engineering problems and methods courses.

During the sophomore year, the student continues his work in mathematics and physics and begins to integrate these sciences with two engineering science courses taught by members of the faculty of the College of Engineering. Included also is a liberal studies elective (liberal studies constitute approximately one-fifth of the engineering curriculum at Cornell). Students who anticipate enrollment in chemical engineering establish earlier chemistry sequences during their sophomore program.

Most students begin to select their upperclass objectives before the beginning of the fall term of their sophomore year. Each professional school specifies one of the two engineering science courses taken by sophomores; the student may choose the other from among the remaining four. This requirement may alternatively be taken either during the spring term of the sophomore year or in the summer session preceding junior enrollment. Through these options students find a choice between several engineering objectives possible as late as the beginning of the junior year.

If a student expresses interest in a particular branch of engineering at the outset, he will be assigned to a faculty adviser whose major interest is in that field. If he does not express a particular interest, then after he determines his field of study, he may change his adviser to obtain the counsel of a faculty member in his chosen field.

Honors Sections and Advanced Placement

Students are normally enrolled in sections of the various courses consistent with their individual level of preparation, and some are thus able to take advantage of special honors groups or programs of advanced study available in their professional fields. Through cooperation with the advanced placement program of the College Entrance Examination Board and departmental tests given during the fall orientation period, normally one-fifth of the class is given advanced placement or actual college credit for one or more courses of the freshman year. This makes possible more individual development toward a broader liberal program, or advanced technical study in line with the student's own inclination. Superior students who have achieved two terms of advanced placement in mathematics and in either chemistry or physics upon graduation from high school, may find it possible to enroll as a sophomore by completing the other science course prior to their enrollment at the University in September. Students with superior performance in the freshman year may enroll in sophomore honors sections. Those students who wish to include more liberal studies may be permitted to take a course overload or to extend their four-term registration in Basic Studies, up to a maximum of two additional terms. A similar extension may be granted to those students who wish to carry four courses per term instead of the usual five.

Scholastic Requirements

The Division of Basic Studies of the College of Engineering normally enrolls all students for five courses each term. All of these must be passed, four with a grade of 70 or better, in order to remain in good standing in the Division. All engineering students are required to complete 24 hours of liberal studies before graduation; six hours of English and six hours of liberal electives must be completed by students in this Division as part of this College requirement. (See Liberal Studies in the Engineering Curricula, page 16, for distribution requirements.)

Freshman Year

Freshman students entering the College of Engineering in the fall of 1965 will take the following program of courses:

		Contact Hours	
	Credit Hours	*Lect. Rec.*	*Lab. Comp.*
FIRST TERM			
Mathematics 191, Calculus for Engineers....	4	3	2
Physics 121, Introductory Analytical Physics	3	3	2½
Chemistry 107, General Chemistry.........	3	2	3
or			
Chemistry 115, General Chemistry and Inorganic Qualitative Analysis.............	4	3	3
English 111, Introduction to English........	3	3	0
Engineering 103, Engineering Graphics......	3	2	2½
or			
Enginering 104, Engineering Problems......	3	2	2½
SECOND TERM			
Mathematics 192 or 192H, Calculus for Engineers	4	3	2
Physics 122, Introductory Analytical Physics..	3	3	2½
Chemistry 108, General Chemistry..........	4	3	3
or			
Chemistry 116, General Chemistry and Inorganic Qualitative Analysis.............	4	2	6
English 112, Introduction to English........	3	3	0
Engineering 103, Engineering Graphics.....	3	2	2½
or			
Engineering 104, Engineering Problems.....	3	2	2½

In addition to these courses, all underclassmen must satisfy the University's requirements in physical education.

Sophomore Year

All sophomore engineering students, except chemical engineering designates, will take the following program of courses:

	Credit Hours	*Contact Hours* *Lect. Rec.*	*Lab. Comp.*
THIRD TERM			
Mathematics 293 or 293H, Engineering Mathematics	4	4	0
Physics 223 or 225, Introductory Analytical Physics	4	3	2½
Liberal Elective *	3 or 4	–	–
Enginering Sciences (two of the following)	6 or 7	–	–
Physical Chemistry 276	(3)	(3)	(0)
Electrical Science 241 or 243	(3)	(2)	(2½)
Mechanics 211	(4)	(3)	(2½)
FOURTH TERM			
Mathematics 294 or 294H, Engineering Mathematics	3	3	0
Physics 224 or 226, Introductory Analytical Physics	4	3	2½
Liberal Elective *	3 or 4	–	–
Engineering Sciences (two of the following)	7 or 8	–	–
Materials Science 6211	3 or 4	–	–
Electrical Science 242 or 244	(3)	(2)	(2½)
Mechanics 212	(4)	(3)	(2½)

Each upperclass Field Program specifies one engineering science which must be successfully completed in order to enroll in the program at the beginning of the junior year. The second required engineering science may be chosen by the student. The specific Field Program requirements are as follows:

Civil Engineering	Mechanics 211–212
Mechanical Engineering	Mechanics 211–212
Enginering Physics	Physical Chemistry 276 – Materials Science 6211
Materials Science and Engineering	Physical Chemistry 276 – Materials Science 6211
Electrical Engineering	Electrical Science 241–242 or 243–244
Industrial Engineering	Any two

Mechanics and electrical science will be offered from fall through summer: Mechanics 211 in the fall and spring and Mechanics 212 in the spring and summer; Electrical Science 241 in the fall and spring and Electrical Science 242 in the spring and summer. This will enable students to have greater flexibility in making program changes.

All sophomore engineering students indicating a preference for chemical engineering will take the following program of courses:

	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
THIRD TERM			
Mathematics 293 or 293H, Engineering Mathmatics	4	4	0
Physics 223 or 225, Introductory Analytical Physics	4	3	2½
Chemistry 285, Introductory Physical Chemistry	5	4	6
Chemical Engineering 5101, Material and Energy Balances	3	3	2
Liberal Elective *	3 or 4	–	–
FOURTH TERM			
Mathematics 294 or 294H, Engineering Mathematics	3	3	0
Physics 224 or 226, Introductory Analytical Physics	4	3	2½
Chemistry 286, Introductory Physical Chemistry	5	4	6
Chemical Engineering 5102, Equilibria and Staged Operations	3	3	2
Liberal Elective *	3 or 4	–	–

* Liberal electives include courses in social sciences, history, humanities, modern foreign languages, and expressive arts (courses such as accounting, management, and law excluded) chosen from a list approved by the Core Curriculum Committee. A total of 24 credit hours are reserved for liberal studies, including 6 credit hours in freshman English and at least 6 of the remaining credit hours in upperclass courses. No more than 6 credit hours may be earned in a modern foreign language.

In addition to the 24 credit hours for liberal studies, there are 6 credit hours for free electives. To satisfy this requirement, a student may take any course at the University to which he can gain admission.

CHEMICAL ENGINEERING

OLIN HALL

Mr. C. C. Winding, Director; Messrs. G. G. Cocks, R. K. Finn, P. Harriott, J. E. Hedrick, J. P. Leinroth, C. W. Mason, F. Rodriguez, G. F. Scheele, J. C. Smith, R. G. Thorpe, R. L. VonBerg, H. F. Wiegandt, L. B. Wingard, R. York.

Chemical Engineering involves the application of the principles of the physical sciences, of mathematics, and of engineering judgment to fields in which matter is treated to effect a change in state, energy content, or chemical composition. Most chemical engineers are employed in the process industries. In these industries, raw materials are converted into useful products such as industrial chemicals, petroleum products, metals, rubbers, plastics, synthetic fibers, foods, paints, and paper. Recently, chemical engineers have been concerned with the problems involved in the development of new plastics, fibers, high-energy fuels, synthetic rubbers, refractory metals, processed foods, and the reduction and use of waste materials. Jet, rocket, diesel and atomic reactor fuels give promise of altering sources of energy for industry and transportation. The synthetic rubbers have released the world from dependency on the rubber plantation. The proper use and disposal of atomic reactor wastes is a necessity for the safety of all concerned. The world's rapidly rising population requires more processed foods and is markedly increasing the need for a reduction in the pollution of air and water in the neighborhood of urban centers. Shortage of good water, already severe in some locations in the world, must be relieved by large economical plants to process sea or other saline water.

Laboratory and Research Facilities

All Cornell programs in chemical engineering, both undergraduate and graduate, are given in Olin Hall of Chemical Engineering. This modern and well-equipped building, with over 100,000 square feet of floor space, provides lecture and recitation rooms as well as laboratories for instruction and research. The main laboratory extends through three floors and contains pilot-plant equipment for undergraduate projects and research as well as space for setting up research apparatus for graduate students. Shops, storage, and service facilities are adjacent to this laboratory. In addition, a large portion of the building is devoted to small unit laboratories containing furniture and equipment suitable for the chemical and bench-scale projects and research carried out by both undergraduate and graduate students. Specialized laboratories are also available. The Geer Laboratory for Rubber and Plastics has facilities for making, processing, and testing all types of polymeric materials. The biochemical engineering laboratory contains equipment for fermentation and other biochemical processes. The process control area is equipped with control instruments, recorders, and computers. A large model shop is used to construct scale models of plant designs.

The Degree Programs

The five-year professional program leading to the degree of Master of Engineering (Chemical) provides a coordinated sequence of chemical engineering courses starting in the second year and extending through the fifth year. Mathematics, physics, mechanics, and electrical science are common with the other divisions of the Engineering College, but the need for greater breadth and depth in chemistry requires additional courses taught by the chemistry department. The courses in chemical processes, materials science, and thermodynamics require sound preparation in chemistry and form an important part of specialized chemical engineering training.

Course programs for Term 1 through 4, administered by the Division of Basic Studies, are described on pages 31–32. Although the student planning to enroll in the five-year professional chemical engineering program remains in the Division of Basic Studies for the first two years, and can transfer to other programs during that time, he selects chemical engineering at the end of the freshman year and registers for Chemistry 285, 286 and Engineering 5101, 5102 during the sophomore year.

Chemical engineering students are required to maintain a 75 average in Terms 5 through 8. Students who achieve a 75 average and receive the approval of the faculty of the School of Chemical Engineering, register in the Graduate School for the fifth year of the five-year professional program. Upon the satisfactory completion of the 30 credit hours specified for the fifth year, students are awarded the degree of Master of Engineering (Chemical).

BACHELOR OF SCIENCE

	Credit Hours	*Contact Hours* Lect. Rec.	Lab. Comp.
TERM 5			
Chemistry 357, Introductory Organic Chemistry	5	3	6
Engineering 5303, Analysis of Stage Processes	3	2	2
Engineering 211, Mechanics	4	3	2½
Engineering 5851, Chemistry Microscopy	3 or 0	1	5
Liberal Elective	3 or 6	–	–
Total	18		

	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
TERM 6			
Chemistry 358, Introductory Organic Chemistry	5	3	6
Engineering 5304, Introduction to Rate Processes	3	2	2
Engineering 5203, Chemical Processes	4	4	0
Engineering 212, Mechanics	4	3	2½
Engineering 5851, Chemical Microscopy	0 or 3	1	5
Liberal Electives	3 or 0	–	–
Total	19		
TERM 7			
Engineering 5103, Chemical Engineering Thermodynamics	3	2	2
Engineering 5353, Unit Operations Laboratory	3	2	3
Engineering 5255, Materials	4	4	0
Electrical Engineering	3	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	19		
TERM 8			
Engineering 5104, Chemical Engineering Thermodynamics	3	2	2
Engineering 5354, Project Laboratory	3	1	5
Engineering 5256, Materials	3	3	0
Electrical Engineering	3	–	–
Free Elective	3	–	–
Liberal Elective	3	–	–
Total	18		
Total for eight terms	142		

MASTER OF ENGINEERING (CHEMICAL)

	Credit Hours	Lect. Rec.	Lab. Comp.
TERM 9			
Engineering 5621, Process Design and Economics	6	4	4
Engineering 5106, Reaction Kinetics	3	3	0
Technical Electives	6	–	–
Total	15		

	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
TERM 10			
Engineering 5622, Process and Plant Design	6	4	4
Engineering 5717, Process Control	3	2	2½
Chemical Engineering Elective	3	–	–
Technical Electives	3	–	–
Total	15		

OPTIONS

Specialized work is offered in biochemical engineering, polymeric materials, process control, reaction kinetics, process and plant design, and process economics. The free electives in the 7th and 8th terms and the nine credits of technical electives in the professional Master's degree program permit a student to select a maximum of 15 credit hours in other divisions of the Engineering College or the University. This choice of electives at an advanced level allows students to arrange programs that are the equivalent of options in either the specializations mentioned above or in other fields such as nuclear engineering, industrial engineering, chemistry, economics, and business administration. The exact sequence of courses to be selected for advanced training is not specified, since it depends on the student's interests and capabilities.

THE COLLEGE PROGRAM: MAJORS AND MINORS

Students pursuing the four-year College Program, described on pages 17 ff., may elect a major or a minor in chemical engineering. These majors and minors require a sequence of chemical engineering courses in the third and fourth years, plus the proper prerequisites, as specified by the student's adviser and the College Program Committee.

PREDOCTORAL HONORS PROGRAM

The Predoctoral Honors Program is available to capable undergraduate students who intend to seek a doctorate. One of the prime objectives of this program is to minimize the time required to obtain this degree, thus increasing the number of Ph.D.'s available for teaching, research, and highly technical positions in industry.

Qualified undergraduates interested in this program may apply for admission during their third year. Evidence of initiative and research ability is required and is considered to be just as important as scholastic standing. Admission to this program must be approved by the faculty of the School, and a student's progress is reviewed at the end of each term.

Students in this program are expected to complete a Master of Science degree during their fifth year rather than the Master of Engineering

(Chemical) program. During the fourth year, a research project is begun in place of the required project-laboratory course. This research continues throughout the fifth year to meet the thesis requirement for the M.S. degree. The electives available during the fourth and fifth year permit the completion of one Ph.D. minor and a start on the second minor. At the end of the sixth year, these students will have completed all the course work required for the Ph.D., and should have enough research experience to select and complete a Ph.D thesis during the following fifteen months. If this program is followed successfully, the doctorate is achieved in three years and one summer beyond the bachelor's degree. The actual courses required during the fourth year in the B.S. program and the fifth year leading to the M.S. are outlined below.

		Contact Hours	
	Credit Hours	*Lect. Rec.*	*Lab. Comp.*
TERM 7			
Engineering 5103, Chemical Engineering Thermodynamics	3	2	2
Engineering 5353, Unit Operations Laboratory	3	2	3
Engineering 5255, Materials	4	4	0
Engineering 5909, Research Seminar	0	1	0
Electrical Engineering	3	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	19		
TERM 8			
Engineering 5104, Chemical Engineering Thermodynamics	3	2	2
Engineering 5952, Research Project	3	0	9
Engineering 5256, Materials	3	3	0
Electrical Engineering	3	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	18		
TERM 9			
Engineering 5106, Reaction Kinetics	3	3	0
Engineering 5631, Separation Processes	3	3	0
Engineering 5900, Seminar	1	1	0
Applied Mathematics	4	4	0
Minor Courses	3	–	–
Total	14		

TERM 10	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
Engineering 5717, Process Control	3	2	$2\frac{1}{2}$
Engineering 5632, Process Evaluation and Design	4	4	0
Engineering 5900, Seminar	1	1	0
Minor Courses	6	–	–
Total	14		

In addition, students will continue their research project throughout terms 9 and 10. Credit hours and grades are not granted for thesis research.

MASTER OF ENGINEERING (CHEMICAL), M.S., AND Ph.D. DEGREES

A student holding a baccalaureate or equivalent degree in chemical engineering from a college of recognized standing may pursue advanced work leading to a professional degree, Master of Engineering (Chemical), or to the general degrees, M.S. or Ph.D., with majors in chemical engineering.

The professional Master's degree requires the successful completion of 30 credit hours of specified courses as outlined on page 22. This Master of Engineering (Chemical) degree is awarded for the successful completion of the five-year professional program in chemical engineering at Cornell, but students from other institutions may also be awarded this degree if they have the proper prerequisites and complete the required 30 credit hours. Cornell chemical engineering graduates who completed the five-year program leading to a B.Ch.E. degree prior to 1966, and who demonstrated aptitude for graduate work, may be awarded the Master of Engineering (Chemical) degree upon the successful completion of 15 additional credit hours as specified by the faculty of the School of Chemical Engineering and approved by the Graduate Programs Committee of the College of Engineering.

The M.S. and Ph.D degrees are administered by the Graduate School and require work in both major and minor fields of study, as well as the completion of a satisfactory thesis involving individual or original research or investigations. A student interested in these degrees should consult the *Announcement of the Graduate School* and *Graduate Engineering at Cornell University* for additional information and for a description of the research interests of the staff of the School of Chemical Engineering.

CIVIL ENGINEERING

HOLLISTER HALL

Mr. N. A. Christensen, Director; Messrs. V. C. Behn, D. J. Belcher, P. P. Bijlaard, G. H. Blessis, W. Brutsaert, H. D. Conway, L. B. Dworsky, M. I. Esrig, G. P. Fisher, C. D. Gates, P. Gergely, W. H. Graf, W. L. Hewitt, T. D. Lewis, T. Liang, J. A. Liggett, W. R. Lynn, G. B. Lyon, W. McGuire, A. J. McNair, A. H. Nilson, W. L. Richards, F. O. Slate, R. N. White, G. Winter, D. A. Woolhiser.

Civil engineering is concerned primarily with the large fixed works and facilities that are basic to community living, industry, and commerce. In a broad sense, the civil engineer learns to control and modify our environment to satisfy the needs and desires of society. In doing so he deals with a wide variety of subfields. He is, for example, responsible for the design not only of the foundations and superstructures of our common structures such as buildings, bridges, dams, tunnels, wharves, etc., but also of many other structures such as rocket installations, containment vessels for nuclear reactors, supports for radio telescopes, frames for aircraft and also for devices used in other branches of engineering.

In addition, the civil engineer must concern himself with the engineering aspects of water resources, rivers, harbors, irrigation, and drainage; with the disposal of wastes and the control of the quality of our air and water; with highways, railroads, pipelines, airports and other transportation facilities; with measuring, mapping, and interpreting the physical conditions of the surface of the earth, often with the aid of electronic methods, photogrammetry, and aerial photographs; and with planning our metropolitan areas and constructing and managing their public facilities.

The work of the individual civil engineer may vary from conception, research, and development to planning, design, construction, and operation, and it frequently involves helping to find solutions to complex social, political, economic, and managerial problems. Accordingly the profession requires the talents of those who are especially expert in one specialty as well as those who can coordinate the over-all efforts on large projects. All civil engineers must be well grounded in mathematics, science, and engineering technology, and all require a broad liberal education to enable them to be effective both as engineers and as citizens. They find employment in government, in private engineering practice, in the construction and manufacturing industries, in utility companies, in education, in sales, and in a variety of other areas.

Laboratory and Research Facilities

Modern, well equipped classrooms and laboratories are available for instruction and research in Hollister Hall, Thurston Hall, and in the Hydraulics Laboratory at Triphammer Falls. These facilities include several laboratories for testing models and full-scale structural assemblies; a concrete laboratory; two hydraulic laboratories; a highway materials and traffic engineering laboratory; sanitary chemistry and microbiology laboratories; a treatment processes laboratory; a soils engineering laboratory; laboratories for engineering analysis and interpretation of aerial photographs; and facilities for preparing maps and processing engineering data by photogrammetric methods. All of these are supported by a machine shop in Hollister Hall.

The Degree Programs

FIELD PROGRAM

The Civil Engineering Field Program includes course work in all departments: Materials, Surveying, Hydraulics, Soils, Sanitary, Transportation, Structures, and Construction Engineering and Administration. In addition, two civil engineering electives permit the student to obtain additional work in a particular area.

To remain in good standing a student must maintain an average of at least 70 per cent each term.

The Bachelor of Science degree serves as one of the prerequisites for the M.S. or M.Eng. (Civil) Degrees.

BACHELOR OF SCIENCE

Civil Engineering Field Program Terms 1 through 4 are described on pages 31–32.

		Contact Hours	
	Credit Hours	*Lect. Rec.*	*Lab. Comp.*
TERM 5			
Geology 103, Geology for Engineers	4	2	5
Engineering 9170, Industrial and Eng. Statistics	3	2	2½
Engineering 2701, Structural Engineering I	3	3	0
Engineering Science (Core Curriculum)	4	3	2½
Engineering Science (Core Curriculum)	3	3	–
Liberal Study (Core Curriculum)	3	–	–
Total	20		
TERM 6			
Engineering 2001, Engineering Materials	3	2	2½
Engineering 2702, Structural Engineering II	3	2	2½
Engineering 2101, Engineering Measurements	3	2	2½
Engineering Science (Core Curriculum)	3	–	–
Engineering Science (Core Curriculum)	3	–	–
Liberal Study (Core Curriculum)	3	–	–
Total	18		

	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
TERM 7			
Engineering 2703, Structural Engineering III	3	2	2½
Engineering 2401, Soils Engineering	3	2	2½
Engineering 2501, Water Supply and Waste-Water Engineering	3	3	–
Engineering 2302, Hydraulic Engineering	3	2	2½
Liberal Study or Free Elective (Core Curriculum)	3	–	–
Engineering 2601, Transportation Engineering	3	2	2½
Total	18		
Term 8			
Civil Engineering Electives	6	–	–
Engineering 2903, Engineering Economy	3	3	–
Liberal Study * (Core Curriculum)	3 or 6	–	–
Free Electives † (Core Curriculum)	6 or 3	–	–
Total	18		

* One course if Liberal Study was elected in Term 7.
† One course if Free Elective was taken in Term 7.

COLLEGE PROGRAM

As an alternative to the Field Program, the student may elect the College Program also leading to a Bachelor of Science Degree. A student with a strong interest in an interdisciplinary and/or specialized program may wish to consider the College Program. Where this involves one of the areas of Civil Engineering, either as a major or minor subject, the various Department Chairmen will be happy to discuss their offerings with the student. This degree also prepares the student for the M.S. or the M.Eng.(Civil) Degree, although the student who elects the College Program will ordinarily apply for the M.S. Degree.

GRADUATE STUDY

The School offers work leading to the degree of Master of Engineering (Civil), the M.S., and the Ph.D degrees. In the field of civil engineering, the following areas of concentration are available either as major or minor subjects: geodetic and photogrammetric engineering, hydraulics, hydraulic engineering, construction engineering and administration, sanitary engineering, sanitary sciences, structural engineering, structural mechanics, soils engineering, transportation engineering, and aerial photographic studies. Descriptions of individual courses are given elsewhere in this Announcement.

The professional program is ideally suited to students planning to enter the professional practice of engineering. The basic quantitative requirement is satisfactory completion of at least 30 credit hours of course work beyond the Cornell four-year program or equivalent in the field of civil engineering. A substantial portion of the work may be in one of the areas of concentration within civil engineering. Graduate level project courses involving several of the following aspects of engineering are also included: feasibility, analysis, design, economics, and systems analysis. In addition, study related to the managerial phases of civil engineering is part of the basic 30 hour requirement.

Prospective graduate students should consult the *Announcement of the Graduate School* and *Graduate Engineering at Cornell University.*

COMPUTER SCIENCE (INTERCOLLEGE DEPARTMENT)

RAND HALL

Messrs. D. Bessel, R. W. Conway, C. Pottle, J. W. Rudan, S. Saltzman, R. J. Walker.

Computer science is a relatively new field of study that draws on and contributes to a number of existing disciplines such as mathematics, engineering, linguistics, and psychology, among others. Developments in this field are also used to make important contributions in research, development, design, and management activities in the various functional areas of engineering and applied science.

At Cornell, computer science is concerned with fundamental knowledge in automata, computability, and language structure, as well as with subjects such as numerical analysis and information processing which underlie broad areas of computer applications. Because of the wide implications of research in the field, the Department of Computer Science is organized as an intercollege department in the College of Engineering and the College of Arts and Sciences. In the Field of Computer Science in the Graduate School, qualified graduate students can earn M.S. and Ph.D. degrees. Although there is no undergraduate field program in computer science in the College of Engineering, it is possible for students in the College Program (described on pg. 17) to develop a course of study that provides an emphasis on computer science and related areas.

Graduate students who are interested in the theory, design, and use of automatic computing equipment as a subject in itself should consider the opportunities for advanced training in computer science. In general, it is expected that they have a strong background in mathematics, science, or engineering, although students with exceptional records from other fields will also be considered for admission. Students with an interest in the application of computers to their own major fields should consider a graduate minor in computer science to supplement and interact with their major field of study. Because of the importance of a strong background in mathematics and engineering sciences, undergraduates in the College Program who are interested in computer science should plan a course of upperclass study that will include work in applied mathematics, probability and statistics, and electrical engineering, as well as appropriate courses in computer science.

Courses in computer science are identified by three digit numbers. The first digit at the left indicates the level of the course:

- 2 — Courses primarily for underclassmen (but may be taken by upperclassmen)
- 3 — Courses primarily for upperclassmen
- 4 — Senior and graduate level courses.

The middle digit indicates the special subject area of the course in computer science:

0 — General
1 — Programming
2 — Numerical analysis
3 — Data processing
4 — Linguistics
5 — Artificial intelligence
6 — Design
7 — Logic and automata

Within this framework, students can develop programs to fit their own interests, with the assistance of the faculty of the Department of Computer Science. In general, engineering undergraduates should take Course 301, Introduction to Computer Science, for their first course.

Computing Facilities

There are extensive computing facilities on the Cornell campus. The Cornell Computing Center has a Control Data 1604 and 160A available for faculty and student use with no outside commitments for these two computers. In addition, IBM 1401 and 1410 computers and an analog computer are operated elsewhere on the campus.

ELECTRICAL ENGINEERING

PHILLIPS HALL

Mr. G. Wade, Director; Mr. J. L. Rosson, Assistant Director; Messrs. P. D. Ankrum, J. M. Ballantyne, R. Bolgiano, N. H. Bryant, G. C. Dalman, N. DeClaris, L. F. Eastman, W. R. Erickson, N. T. Gaarder, A. S. Gilmour, T. Gold, W. E. Gordon, C. F. Green, R. L. Gunshor, C. E. Ingalls, F. Jelinek, M. Kim, K. R. Kleckner, R. L. Liboff, S. Linke, L. A. MacKenzie, H. S. McGaughan, P. R. McIsaac, T. McLean, C. W. Merriam, W. E. Meserve, S. K. Mitra, B. Nichols, R. E. Osborn, C. Pottle, E. L. Resler, Jr., G. C. Rumi, H. G. Smith, E. M. Strong, R. N. Sudan, C. L. Tang, J. S. Thorp, H. C. Torng, N. M. Vrana, L. S. Wagner, H. R. Witt, G. J. Wolga, S. W. Zimmerman.

The curriculum leading to the degree of Bachelor of Science in the Field Program of the School of Electrical Engineering is intended to create in the student an understanding of the meaning and the application of those physical laws that are basic to electrical engineering and, at the same time, to provide the opportunity for as much study in the fields of humanities and social studies as is consistent with the objectives of modern education in the field of engineering. The successful completion of this degree program enables the student to follow one of three possible routes to advanced studies. They are:

1. Graduate studies in the field of electrical engineering leading to the degree of Master of Engineering (Electrical), M.Eng.(E.). This degree is awarded for successful completion of a curricular program and is intended for a student who expects to practice electrical engineering as a profession but does not plan to engage in research as a career. (See page 00 of this announcement for a general description of these requirements.)

2. Graduate studies leading to a degree of Master of Science. This is a research degree that involves residence on the campus and submission of a thesis and is intended for students who plan to engage in research as a career. The requirements for this degree are described in the *Announcement of the Graduate School.*

3. Advanced studies in fields other than engineering such as law and business administration.

The education of the modern electrical engineer, as represented by the successful completion of the requirements for the degree of Master of Engineering (Electrical), provides a sound foundation for him to practice electrical engineering successfully in a rapidly expanding field (that includes such recently developed areas as biomedical electronics, quantum electronics, plasma physics and magnetohydrodynamic power generation, space communication and control, computer design, and molecular electronics) and for engineering functions that range from research to production. In establishing this curriculum, the faculty of the School of Electrical Engineering has recognized the enormous scope of electrical engineering today and has concluded that three main themes are necessary to prepare its students adequately. These themes are called *Electrophysics, Systems,* and *Laboratory.* They are interrelated and the curriculum contains an integrated series of required courses in each.

Electrophysics is chiefly concerned with our present understanding of the physical laws that govern the design or application of electrical devices. Modern devices from machines to lasers — and those in the process of development — are based on the laws governing electric and magnetic fields, interaction of fields and particles, fluid flow, kinetic theory, thermodynamics, quantum mechanics, properties of materials in the solid state, and plasmas. In the curriculum, these subjects are treated in significantly greater depth and breadth than ever before.

The *Systems* sequence deals with the laws that govern the interaction of devices whose individual behavior is specified, as well as the response of these systems to various inputs. These systems may be solely electrical or involve transducers; they may contain both linear and nonlinear elements; they may be passive, active, or random. Systems may be used for many purposes, e.g., power distribution control, communications, and instrumentation. The course program is designed to develop the general methods of analysis required for all such systems together with understanding of the physical significance of the solutions.

The *Laboratory* sequence emphasizes that new developments in engineering practice come from a blend of theory and experimentation. Laboratory work brings students into close touch with reality in the areas of both systems and electrophysics. The experimental work may be based on the analysis developed in one of the areas or in neither. The curriculum contemplates an expansion of the time normally spent by the student in the laboratory. Each of the four laboratory courses involves two laboratory periods per week. There are sufficient time and flexibility to allow individual exploration, and the goal is to enable the student to devise his own experiments.

The Degree Programs

BACHELOR OF SCIENCE (FIELD PROGRAM)

Term	*Systems* *	*Electrophysics* *	*Laboratory* *	*Other Requirements* †
5	4301: Linear Passive Networks (4)	4311: Electromagnetic Waves (4)	4321: El. Lab. I (4)	2 courses minimum 6 hrs.
6	4302: Introd. to Active Systems (4)	4312: Applied Thermodynamics (4)	4322: El. Lab. II (4)	2 courses minimum 6 hrs.
7	4401: Linear System Analysis (4)	4411: Quantum Theory (4)	4421: El. Lab. III (4)	2 courses minimum 6 hrs.
8	4402: Active Systems (4)	4412: Solid State Physics (4)	4422: El. Lab. IV (4)	2 courses minimum 6 hrs.

* Credit hours indicated in parentheses.

† The requirements of engineering science and liberal electives are specified on page 15 which describes the Core Curriculum. Six hours of the requirements for engineering science are to be met by the required courses of the E.E. Field Program.

SCHOLASTIC REQUIREMENTS

A student failing to make satisfactory progress toward his degree, evidenced by a low average, by course failures, or by low grades in major courses, may be given a trial term or dropped from the School.

FIELD ELECTIVE COURSES

The curriculum of the School of Electrical Engineering provides for a wide selection of elective technical courses which may be incorporated into the Field Programs of the students. The selection of these courses can begin with Term 7. It is hoped that students will use these elective courses to pursue effectively their individual interests in the Field Program of Electrical Engineering.

For the elective courses listed in the electrical engineering section in the Description of Courses section of this Announcement, the digits in the four digit course number have significance as follows:

First digit: the 4 signifies that the course is taught in the School of Electrical Engineering.

Second digit: signifies the year-level of the course. Thus, a 4 means that the course may be taken by a student who is in his fourth year or beyond.

Third digit: signifies the course-group in which the course is considered to be assigned. Thus, a 3 means that the course is in the semiconductor and quantum electronics group.

Fourth digit: signifies the term in which the course is offered. If the digit is odd, the course is offered in the fall term; if even, the spring term. In general, a 0 means either term.

SEMICONDUCTOR AND QUANTUM ELECTRONICS

4531 Quantum Electronics I
4532 Quantum Electronics II
4533 Semiconductor Electronics I
4534 Semiconductor Electronics II
4535 Infrared and Optical Properties of Solids

POWER SYSTEMS AND MACHINERY

4441 Contemporary Electrical Machinery I
4442 Contemporary Electrical Machinery II
4443 Power System Equipment
4444 High Voltage Phenomena
4543 Unified Theory of Electro-Mechanical Systems
4545 Elements of Power-System Analysis

MICROWAVE AND PHYSICAL ELECTRONICS

4452 Physical Electronics
4461 Electromagnetic Theory
4553 Microwave Electronics Laboratory
4554 Physical Electronics Laboratory

WAVE PROPAGATION AND PLASMA PHYSICS

4461 Electromagnetic Theory
4462 Wave Propagation in the Atmosphere I
4561 Plasma Physics I
4562 Plasma Physics II
4566 Wave Propagation in the Atmosphere II
4661 Kinetic Equations
4662 Kinetic Theory of Plasma

SYSTEMS

4503 Theory of Linear Physical Systems
4504 Theory of Nonlinear Systems I
4571 Network Theory
4572 Network Synthesis
4573 Random Processes in Electrical Systems I
4574 Random Processes in Electrical Systems II
4581 Feedback Control Systems I
4582 Feedback Control Systems II
4583 Analog Computation I
4584 Optimization Techniques in Control Systems
4587 Switching Systems I
4588 Switching Systems II
4670 Advanced Topics in System Theory
4671 Theory of Nonlinear Systems II
4673 Random Processes in Communication Systems
4674 Transmission of Information
4681 Random Processes in Control Systems

MASTER OF ENGINEERING (ELECTRICAL)

The degree of Master of Engineering (Electrical) is available as a curriculum type of professional degree at the Master's level in the Field of Electrical Engineering. To enter this program, a student must first be accepted by the Graduate School for admission as a candidate.

Term	*Systems* *	*Electrophysics* *	*Electives*
9	4501: Systems with Random Signals (4)	4511: Electrodynamics (4)	See note (†) below.
10	4502: Statistical Aspects of System Analysis (4)	4512: Fields, Waves, and Electrons (4)	See note (†) below.

* Credit hours indicated in parentheses.

† A total of 14 credit hours must be elected. Of this total a minimum of 6 hours must be in electrical engineering. The remaining credit hours may be selected from engineering, mathematics, or physics.

M.S. AND Ph.D DEGREES

The requirements for the degrees of Master of Science and Doctor of Philosophy are described in the *Announcement of the Graduate School.*

These are research degrees that involve residence on the campus and submission of a thesis.

In the School of Electrical Engineering, research work leading to these degrees may be undertaken in the area of *electrophysics* including radio propagation, radio and radar astronomy, plasma physics, magnetohydrodynamics, physical and microwave electronics, materials science in electrical engineering, quantum electronics, biomedical electronics, electric power conversion, electrical breakdown phenomena, etc., and in the area of *systems* including information theory, network theory, communications systems, control systems, switching circuits, computers, cognitive systems, etc. A number of fellowships, research assistantships, and teaching assistantships are available to candidates for the degrees of Master of Science and Doctor of Philosophy who are doing their thesis research in the School of Electrical Engineering. Assistantship applications and further information can be obtained by writing to the Coordinator of Graduate Studies, School of Electrical Engineering.

ENGINEERING PHYSICS

ROCKEFELLER HALL

Mr. J. P. Howe, Director; Mr. T. R. Cuykendall, Associate Director, Messrs. B. W. Batterman, K. B. Cady, D. D. Clark, D. R. Corson, E. T. Cranch, D. E. Fisher, L. H. Germer, T. Gold, P. L. Hartman, J. A. Krumhansl, P. J. Leurgans, M. S. Nelkin, H. F. Newhall, E. L. Resler, Jr., T. N. Rhodin, H. S. Sack, W. R. Sears, B. M. Siegel, J. Silcox, A. Taylor, W. W. Webb, G. J. Wolga.

Creativity and innovation in engineering and applied science depend significantly on basic and advanced knowledge in physics and applied mathematics and on the techniques of applying this knowledge to engineering problems. Accordingly the engineering physics program provides this kind of knowledge, encourages this approach among students with an interest and competence for such areas. It seeks to prepare students for the continually widening engineering challenges that have deepening roots in fundamental knowledge produced by physical research.

The student pursues thorough and advanced courses in physics and applied mathematics. He is encouraged to develop insight into the application of concepts. To this end, his curriculum includes a core of engineering sciences and a systematic development of electrical and electronic systems. Thus he may proceed from a basic understanding of matter and energy through a knowledge of techniques to a number of applied themes. By selecting electives, he opens for himself the way to several modern technological areas such as recent advances in gas-dynamics, aerodynamics, plasmas, radio astronomy, astrophysics, other space sciences, modern topics in solid state physics systems development and nuclear science and engineering.

Study in this field provides a sound foundation for graduate study in physics, applied physics, nuclear science and engineering, aerospace engineering, and in other areas of engineering research based on physics and applied mathematics. Also, the curriculum has proved to be an excellent foundation for employment in the newer technological industries that transcend the boundaries of the established engineering professions. Therefore, students in the program have the opportunity to qualify for: (1) the "fifth year" professional Master of Engineering programs in engineering physics, nuclear engineering, and aerospace engineering, each created for those who wish to practice the newer applications of physical science; (2) further education in professional fields enriched by a background in applied science; or (3) positions in industry at the end of four years, usually to continue learning on the job and often to participate in advanced training programs.

Laboratory and Research Facilities

The activities of the department are housed in Rockefeller and Clark Halls, which are connected and which also house the Department of

Physics, and in the Nuclear Reactor Laboratory. Rockefeller Hall is the center for undergraduate affairs, such as student advising. Graduate activities and research are under way in all three buildings.

The department is fully equipped for project and research studies in the areas of electron microscopy and diffraction, solid state and surface physics, low energy nuclear physics, nuclear chemistry and nuclear reactor physics and technology.

Five commercial electron microscopes are in use in the department. Ultra high resolution instruments for atomic and molecular microscopy are being developed. Super-conducting and magnetic phenomena are being studied at very low temperatures. Apparatus and equipment for studying nuclear phenomena are extensive and are described on page 13.

The Degree Programs *

Of the core engineering sciences that may be completed before the end of the fourth semester in the Division of Basic Studies, the physical chemistry-materials science sequence is required. Electrical science is also strongly recommended. The faculty and students have found that familiarity with the phenomena occurring in materials and in electrical systems provides a good basis for building deeper and wider understanding as well as sound applications. The relationship between interest and proficiency in physics and mathematics at this stage and further progress is obvious.

Initiation of the study of a specialty is encouraged through courses such as Physics 444, Nuclear Physics, or Engineering 8302, Nuclear and Reactor Physics, Physics 454, Solid State Physics, and additional topics in Physics 410, Advanced Physics Laboratory.

By suitable selection of technical electives during his last two years the qualified student may prepare for a career in one of the many specialized fields of engineering. As examples, four possible programs are outlined:

AEROSPACE ENGINEERING (see page 80). The undergraduate program in engineering physics is particularly suited for work in aerospace engineering either at the undergraduate or at the graduate level.

NUCLEAR ENGINEERING. The student interested in the nuclear energy field, or in nuclear reactor power developments, should choose his electives from courses in reactor physics, nuclear measurements, advanced heat transfer, and in physics of solids underlying radiation damage problems. His attention is directed to courses 8302, 8309, 8312, 8351, 8352, and to 3665, 5760, 6872, and 7201, which are described in de-

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* Attention is called to the fact that change to a new curriculum is in progress. As a result the detailed curriculum may vary for each class.

tail in the section, "Description of Courses." Additional closely related courses such as Physics 444 are also available.

MATERIALS SCIENCE. The core program of the engineering physics curriculum combined with electives in engineering physics (e.g., 8262, 8512), materials and metallurgy, and with specialized seminars provides an excellent preparation for research in materials science, a field that often holds the key to further technological progress. Students can find ample possibilities for senior projects by joining one of the active research groups studying such topics as surface physics, properties of thin films, electron microscopy and diffraction, relaxation phenomena and their relation to dislocations and other defects, photoconductivity, and others.

SPACE SCIENCE AND TECHNOLOGY. Engineering physics provides an excellent preparation for undergraduate or graduate specialization in this challenging field. Qualified students may elect courses in gas-dynamics, radio wave propagation, optics, astronomy, relativity, and other related courses. Several faculty members have strong research interests in this field and are available to supervise senior research projects related to their areas of specialization. Students may undertake projects as a part of the work of the Center for Radiophysics and Space Research.

SCHOLASTIC REQUIREMENTS

A student is expected to pass every course for which he is registered, to maintain each term a weighted average of about 75 per cent or better, and to demonstrate aptitude and competence in the basic subject matter of the curriculum.

A student failing to satisfy these requirements may be put on probation or refused permission to continue his studies in the Department.

BACHELOR OF SCIENCE

The Bachelor of Science in engineering and preparation for graduate work in the Fields mentioned above may be obtained by satisfactorily completing the following curriculum or its equivalent. (Terms 1 through 4 are described on pages 31–32).

		Contact Hours	
	Credit Hours	*Lect. Rec.*	*Lab. Comp.*
TERM 5			
Mathematics 421, Applied Mathematics	4	4	0
Physics * Introduction to Theoretical Physics I	3	3	0
Physics * Applied Physics	3	3	0
Engineering † Electrical Systems (and laboratory)	4	3	2½
Liberal Elective	3 or 4	–	–
Total	17 or 18		

	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
TERM 6			
Mathematics 422, Applied Mathematics	4	4	0
Physics * Introduction to Theoretical Physics II	3	3	0
Physics * Modern Physics	3	3	0
Engineering † Electrical System (and laboratory)	4	3	2½
Seminar for Juniors, areas of Applied Science	1	1	0
Liberal Elective	3 or 4	–	–
Total	17 or 18		
TERM 7			
Mathematics 423, Applied Mathematics	4	4	0
Physics 443, Atomic Physics and Introduction to Quantum Mechanics	3	3	0
Engineering 8121, Thermodynamics and Fluid mechanics	3	3	0
Free Elective	3	–	–
Liberal Elective	3 or 4	–	–
Total	17 or 18		
TERM 8			
Physics 444, Nuclear or High Energy Particle Physics or	4	4	0
Physics 454, Solid State Physics or			
Engineering 8309, Low Energy Nuclear Physics	3	0	0
Physics 410, Advanced Experimental Physics	4	1	6
Engineering 8122, Thermodynamics and Fluid Mechanics	3	3	0
Free Elective	3	0	0
Liberal Elective	3 or 4	0	0
Total	17 or 18		

* These courses in Modern and Theoretical Physics cover approximately the objectives and subject matter of Physics 337, 338, portions of Engineering 7301, Continuum Mechanics, described in the 1964–65 Announcement, together with additional topics in analytical mechanics.

† These courses have similar objectives and cover approximately the same topics as Engineering 4302, 4402 and 4321 in the 1964–65 Announcement.

The College Program, leading to the degree of Bachelor of Science, may be pursued through a suitable selection of courses and themes in physics and applied physics. Such a program must be approved after formulation by the student and cannot be specified in approved form in advance. Some partial course combinations of possible interest are:

MAJOR IN NUCLEAR ENGINEERING

Physics 436, Modern Physics
Engineering 8302, Nuclear and Reactor Physics
Engineering 8351, Nuclear Measurements Laboratory
Engineering 5760, Nuclear and Reactor Engineering
Engineering 6872, Nuclear Materials

MINOR IN NUCLEAR ENGINEERING

Physics 436, Modern Physics
Engineering 8302, Nuclear and Reactor Physics
and either
Engineering 8351, Nuclear Measurements Laboratory
or
Enginering 6872, Nuclear Materials

MAJOR IN ENGINEERING PHYSICS

Physics 337, Intermediate Analytical Physics I
Physics 338, Intermediate Analytical Physics II
Physics 443, Atomic Physics and Introduction to Quantum Mechanics
Physics 410, Advanced Experimental Physics

MASTER OF ENGINEERING (ENGINEERING PHYSICS)

The objectives of the four year engineering physics program are well served by an additional year of advanced study and by the initiation of individual and independent work. The student has the opportunity to master advanced topics in physics and can extend his skill in his chosen engineering specialties. He must carry out an independent project that provides experience in defining objectives, making plans, prosecuting a program and reporting conclusions. Thus he is expected to develop and display the skills and the responsibility needed for working independently or cooperatively toward engineering goals without firmly prescribed guide lines other than his own knowledge and judgment.

From the Master's Program the student may move into development work, for example in industry, or he may go on to more advanced graduate study.

Most of the laboratory facilities for research in the areas described above are made available for the student projects required for the M.Eng. degree. Each project is supervised by a member of the faculty active in the subject.

Admissions Requirements

1. For Cornell students: A cumulative average of 75 or better in the four-year Field Program in engineering physics will allow admission without petition.

2. For transfer students: Evidence is required that the candidate has the ability and preparation to complete successfully the program of study.

Requirements for the Degree

1. A six-hour project, which requires individual effort and a formal report, and which may be either experimental or analytical.

2. (a) If the project is experimental, one course in mathematics or applied mathematics; or (b) if it is analytical, one term of advanced laboratory, Physics 510, or an equivalent laboratory course taken from a list to be drawn up by the Curriculum Committee of the Department.

3. Physics 572, Quantum Mechanics.

4. A minimum of six hours in an engineering course sequence.

5. Chemistry 380, 596 or a new equivalent course to be arranged.

6. A one-hour seminar course – a modified version of 8252.

7. Technical electives to bring the total credit hours to 30.

MASTER OF ENGINEERING (NUCLEAR)

Nuclear engineering is concerned with the practical application of scientific knowledge of nuclear reactions and radiations. In this broad context nuclear engineering treats the production and use of the energy of nuclear fission, the production of neutrons, gamma radiation, radioisotopes, and transmutation of elements. The aims of the program at Cornell are to provide the student with a thorough understanding of the laws and principles upon which our understanding of nuclear systems is based, and to develop the skills of applying basic principles to engineering problems. The nuclear engineering program includes class instruction, experimental and theoretical research, and engineering synthesis and design.

Nuclear engineering uses the basic sciences of chemistry, physics, and mathematics, and the skills of metallurgical, chemical, civil, electrical, and mechanical engineering. The nuclear engineering faculty is made up of members from each of these engineering fields as well as from engineering physics.

The primary facilities for nuclear engineering research are housed in the Nuclear Reactor Laboratory supervised by the Department of Engineering Physics. These facilities include the following: (1) A TRIGA nuclear reactor with a steady state power of 100 kw providing sources of neutrons and gamma rays for activation analysis or solid and liquid state physics studies; (2) A critical assembly or "zero power reactor" of versatile design for basic studies in reactor physics and dynamics (this is the only operating critical assembly in any university); (3) Subcritical assemblies for reactor physics investigations; (4) A shielded cell with 10,000 curies of Co^{60} gamma sources for radiation chemistry studies; (5) A radio-chemistry laboratory; and (6) A 3 MeV Cockcroft-Walton accelerator for radiation effects and low energy nuclear reaction studies.

Admissions Requirements

The nuclear science and engineering faculty at Cornell believes the specialized education of nuclear engineers lies at the graduate level; for this reason no Bachelor of Science program in the nuclear field is offered. Appropriate undergraduate programs which can lead to graduate study in nuclear engineering are civil, chemical, electrical, or mechanical engineering, or engineering physics. In addition, the College Program offers a wide range of majors in the above fields as well as a nuclear engineering major within the engineering physics field. Individuals preparing for graduate study in nuclear engineering should select their technical electives carefully in order to insure that they meet the entrance requirements for the graduate program. Whether or not a student is preparing for graduate study in nuclear engineering, there are a number of courses in the nuclear field available to him as technical electives. These courses are described under the specific engineering field which is in charge of the course content.

Graduate study in nuclear engineering is possible in three separate programs: Master of Engineering (Nuclear), Master of Science, and Doctor of Philosophy.

The professional Master's degree program is being offered for the first time in 1965–66 and is intended primarily for students who want a terminal degree, and secondarily for students who want an interim degree before doctoral study in nuclear science or engineering. The entrance requirements include:

1. A baccalaureate degree in engineering, applied science, or its equivalent,
2. Physics, three years including atomic and nuclear physics,
3. Mathematics, three years including one year of advanced calculus,
4. Thermodynamics.

Students should make every effort to take these subjects before starting graduate study. Students with minor deficiencies may make them up after admission to graduate study, but they may need more time to complete the graduate program.

Requirements for the Degree

For Master of Engineering (Nuclear) the following courses are required:

FALL TERM

EP 8309, Low Energy Nuclear Physics
EP 8333, Nuclear Reactor Engineering
Engineering
Mathematics or Physics

SPRING TERM

EP 8351, Nuclear Measurements Laboratory
EP 8312, Reactor Theory I
Engineering
Enginering Design Project

The courses labeled "engineering" above are to be in a subject area relevant to nuclear engineering (e.g. nuclear materials, nuclear chemical engineering, fluid dynamics, heat transfer, energy conversion, automatic feedback control systems).

M.S. AND Ph.D. DEGREES IN APPLIED PHYSICS

The faculty of the Department of Engineering Physics is associated with the Field of Applied Physics in the Graduate School. The objectives and nature of this Field are an extension of those of the undergraduate program into the realm of original research. They are described in the *Announcement of the Graduate School.* Major purposes are to afford creative students with a background in physics the opportunity to carry their training to the point of making original applications and to allow students with originality and training in engineering to acquire a deep knowledge of physics.

Examples of research studies now under way, using facilities mentioned earlier, are: development of an electron microscope system capable of resolving approximately 2×10^{-8} cm; application of electron microscopy to biologically important molecules and structures; use of electron scattering and optics in the study of the magnetic structure of superconducting and magnetic solids; structure of substances near the critical temperature; use of low energy electron diffraction and field ion microscopy in the study of atomic arrangements and reactions on the surface of solids; effects of high energy radiation on solids; and theory of the dynamical behavior of liquids. Through association with faculty from other departments, topics such as lasers, plasma dynamics, theory of solids, and theoretical mechanics may be pursued.

Requisites for entering graduate study in the Field of Applied Physics may be found in the *Announcement of the Graduate School,* which also lists opportunities for financial support. Applications and requests for further information may be addressed to the Field Representative, Applied Physics, Department of Engineering Physics, Rockefeller Hall.

Courses of study for the degree are not prescribed, and the Graduate School imposes few specific subject requirements. Individual programs of formal or informal study are settled between a student and a special committee of his own selection.

M.S. AND PH.D. DEGREES IN NUCLEAR SCIENCE AND ENGINEERING

A candidate for either degree may choose, as his major subject, nuclear science or nuclear engineering. The detailed program of studies is not prescribed as a curriculum. Each student's program is worked out individually with the members of his Special Committee as mentioned above. Areas of research in nuclear science include nuclear chemistry, low energy nuclear physics, theory of neutron interactions with matter, radiochemistry, radiation chemistry, nuclear cosmo-chemistry, activation analysis, and radiation detection. Areas of research in nuclear engineering include neutral particle transport theory, reactor statics and dynamics, nuclear materials and fuels, basic processes in the production and use of power from nuclear reactions, and selected problems in nuclear reactor design and optimization. More complete information on M.S. and Ph.D. programs is available in the *Announcement of the Graduate School.* Applications for admission should be addressed to the Field Representative, 116 Nuclear Reactor Laboratory.

INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

UPSON HALL

Mr. B. W. Saunders, Director; Messrs. R. N. Allen, R. E. Bechhofer, R. H. Bernhard, R. W. Conway, H. P. Goode, D. L. Iglehart, W. L. Maxwell, J. W. Rudan, S. Saltzman, M. W. Sampson, A. Schultz, Jr., H. M. Taylor III, L. I. Weiss.

Industrial engineering involves the analysis, design, and operation of integrated systems of men, materials, and equipment to perform a useful function. Operating systems which appear to be very different from each other may have a number of common characteristics which make them typical industrial engineering problems. For example, the determination of the number of toll booths which should be placed at the entrance to a turnpike or tollbridge, the type of maintenance system to be used in a mass production plant, the design of a telephone system to handle customers in a sales office, and the policies to be followed in assignment of runways at a busy airport all seem to be very different problems. Yet, every one of them involves a facility of some sort which provides service to a series of inputs or customers. This identifies it as a queuing problem which may be analyzed with well known industrial engineering techniques involving, in some cases, mathematical theory and models and the utilization of a digital computer.

Another group of operating systems which have common characteristics would include such things as the design of an inventory control system for a manufacturing organization, determination of the size of an airplane to use on a particular run, establishing a replacement policy for production machines, and planning what volume of foods to purchase for a busy restaurant. These problems involve the stocking of commodities for which the demand is uncertain. In each case the cost of securing and holding an item is balanced against the level of service to be provided. These characteristics identify these problems as ones involving inventory theory, and they can be analyzed using the techniques which have been developed for inventory problems.

Prior to 1950 nearly all industrial engineering work took place in the mechanical manufacturing industries. Today, developments in the field have been so extensive that analytical methods and design techniques used by industrial engineers are as applicable in service industries, government, and institutional operations as they are in manufacturing. Indeed, the scope of work has tended to outgrow the designation "industrial engineering," and this type of work often is identified by other names. Many schools and organizations use the "operations research" to cover approximately the same activity. Other terms frequently used include "operations analysis," "systems analysis," "systems engineering," and "management science." It is not meant to imply that these names are all completely synonomous, but rather that there is a high degree of overlap in the areas covered by terms for which there is no universally accepted meaning and which are used by different individuals and groups in quite different ways. "Industrial engineering" is used at Cornell because here the emphasis is on both the analysis *and* synthesis leading to the design of the facilities and procedures necessary to make an efficient operating system serving some needed function.

Following the first two years of work in the Division of Basic Studies, the curriculum leading to the professional degree in industrial engineering, Master of Engineering (Industrial), develops the necessary background in probability, statistics, computing, and cost analysis in the third year and goes into considerable depth in analysis, design, model building, and experimental methods in the fourth year. Students satisfactorily completing the work of these four years are awarded a Bachelor of Science degree. Qualified candidates may then continue with the fifth year of study which includes a two-term project and a number of applied analytical courses which are closely integrated with the work of the previous four years. The required courses coupled with a well-planned elective program permit the student to develop a course of study of considerable breadth or depth to suit his own interests and needs.

Laboratories and Research Facilities

The program in industrial engineering is under the direction of the Department of Industrial Engineering and Operations Research, with offices and class rooms in Upson Hall. Facilities include some conference-type class and seminar rooms, a methods laboratory, and computing rooms containing adding machines and desk calculators. However, the basic laboratory for the department is the Cornell Computing Center described on page 13. As mentioned elsewhere, every engineering student at Cornell learns how to program problems for the computer in his freshman year. Students in industrial engineering are required to learn considerably more about computer science, with problems requiring use of a high speed digital computer assigned in many of the courses. In addition, term projects, graduate theses, and a considerable amount of departmental research utilize computer time to the extent that the department has consistently been one of the largest users of the computer on the campus.

The Degree Programs

BACHELOR OF SCIENCE

The first four terms are described on pages 31–32 of this Announcement. The DBS program specifies two engineering science courses in each term of the sophomore year. For industrial engineering students, these can be any two that are offered. The remaining two should then be scheduled during the junior year in order to delay electives until the senior year when a wider choice will be available because of more complete preparation to that point.

TERMS 1–4

See Division of Basic Studies Curriculum on pages 31–32.

	Credit Hours	*Contact Hours* *Lect. Rec.*	*Contact Hours* *Lab. Comp.*
TERM 5			
Engineering Science *	3	–	–
Engineering 3630, Thermal Science I †	3	3	–
Engineering 9301, Introduction to Industrial Engineering	1	1½	–
Engineering 9350, Cost Analysis and Control	4	3	2½
Engineering 9360, Probability Theory	4	3	2½
Liberal Elective	3	3	–
Total	18		
TERM 6			
Engineering Science *	3	–	–
Engineering 3631, Thermal Science II †	3	3	–
Engineering 9302, Manufacturing Problems	2	1	2½
Engineering 9370, Statistical Theory	4	3	2½
Enginering 9381, Introduction to Computer Science	3	2	2½
Liberal Elective	3	3	–
Total	18		
TERM 7			
Engineering 9310, Industrial Engineering Analysis	4	3	2½
Engineering 9320, Industrial Engineering Models	4	3	2½
Technical Elective	3	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	17		

* This will be the third engineering science course mentioned above and not taken in the second year.

† Thermal Science is the fourth of the sequence of the required engineering science courses. This course will not be available in the sophomore year in 1965–66, hence is listed explicitly as a third year course.

Note that students are permitted to take four-credit hour elective courses in place of three-credit hour courses where they so desire.

TERM 8	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
Engineering 9303, Industrial Engineering Laboratory	4	2	5
Engineering 9311, Industrial Engineering Design	4	2	5
Technical Elective	3	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	17		

Scholastic Requirements

A student in the Department of Industrial Engineering and Operations Research who does not receive a passing grade in every course for which he is registered, who fails in any term or summer session to maintain an average grade of C, or who is not otherwise making substantial and steady progress toward the completion of his degree requirements, may be dropped or placed on probation.

Elective Courses

The industrial engineering curriculum is specifically designed to provide in its elective content considerable flexibility in both technical and liberal courses. It includes a minimum of 30 elective credit hours (including 6 hours taken in the Division of Basic Studies) divided into 18 liberal, 6 technical and 6 free. This permits students with widely varying interests to develop programs which meet their own needs. For example, the student may utilize the 6 technical and 6 free electives to take 12 hours of work in one technical area. This may be in some phase of industrial engineering or it may be in another engineering field. For illustration: a student might take a concentration of courses in machine design (mechanical engineering), in sanitary engineering (civil engineering), or in the systems sequence of electrical engineering. That is possible and logical because the analytical methods of industrial engineering lend themselves to work in virtually every engineering field as demonstrated by the very wide variety of jobs presently held by industrial engineering graduates. Many other possibilities exist.

These same hours when properly planned can be very effectively used to reduce the time required for graduate study in other fields such as Business and Public Administration or City and Regional Planning. These possibilities are described more explicitly in the following section on Graduate Study, but are made possible because of the relevance of the analytical methods used in industrial engineering to problems found in these fields also.

MASTER OF ENGINEERING (INDUSTRIAL)

The professionl Master of Engineering (Industrial) degree program is designed for those primarily interested in becoming proficient in the practice of modern industrial engineering. This is a formal "course" program which concentrates on additional analytical and design techniques with special emphasis on their application. Details of the program are shown below. To be accepted as a candidate for the Master of Engineering degree, an applicant must (1) hold a Bachelor's degree from an institution of recognized standing in one of the fields of engineering; (2) have an adequate preparation for graduate study in industrial engineering; and (3) show promise of doing well in advanced study as judged by his previous scholastic record or other achievements.

		Contact Hours	
	Credit	*Lect.*	*Lab.*
FALL TERM	*Hours*	*Rec.*	*Comp.*
Engineering 9526, Mathematical Models ...	4	3	2½
Engineering 9580, Systems Simulation	4	2	2½
Engineering 9598, Project	2	As arranged	
Design Course (Selected from I.E. or other approved engineering design courses)	3	Varies with course	
Professional Elective	3	Varies with course	
Total	16		
SPRING TERM			
Engineering 9501, Engineering Administration	3	3	–
Engineering 9521, Production Planning and Control	4	3	2½
Engineering 9599, Project	4	As arranged	
Professional Elective	3	–	–
Total	14		

M.S. AND PH.D. DEGREES

The Master of Science and Doctor of Philosophy programs are designed for those primarily interested in teaching or in academic or industrial research. A student matriculating for one of these degrees may concentrate his studies in any one of several subjects such as industrial engineering, operations research, systems analysis and design, applied probability and statistics, and information processing. To be accepted as a candidate for the Master of Science or Doctor of Philosophy degree in one of the subjects of concentration, the applicant must have been graduated from an institution of recognized standing with a Bachelor's degree in engineering, mathematics, or the physical sciences. In addition he must have had a superior undergraduate scholastic record as evidence of his ability to pursue advanced study and research in the selected field. In case any doubt exists that these requirements are met, it is suggested that the student take the Graduate Record Examination of the Educational Testing Service and have the results sent to Cornell.

These graduate programs rely heavily on the very extensive academic resources of the University. The presence on the campus of the professional Schools of Business and Public Administration, Industrial and Labor Relations, and of City and Regional Planning as well as such departments in the College of Arts and Sciences as mathematics, economics, psychology, and sociology provide students with an extremely wide range of courses from which to draw. For example, one doctoral candidate might have a major concentration in systems analysis and design and select his minor concentrations in mathematics and econometrics while another might build a program combining industrial engineering, psychology, and applied statistics.

For further information about each of these graduate programs see the brochure entitled *Graduate Work in Operations Research, Industrial Engineering, Applied Statistics, and Related Areas,* which may be obtained by writing to the Head of the Department of Industrial Engineering and Operations Research, Upson Hall.

OTHER PROFESSIONAL GRADUATE PROGRAMS OF SPECIAL INTEREST TO INDUSTRIAL ENGINEERS

The undergraduate curriculum in the Field of Industrial Engineering provides a very sound base for two other professional Master's degree programs available at Cornell. One, the Master of Regional Planning (M.R.P.), is offered by the Department of City and Regional Planning of the College of Architecture and is described in detail in the Announcement of that College. By proper selection of elective courses coupled with the required courses in industrial engineering, it should be possible to complete this program in three additional terms beyond the B.S. degree. This field is particularly challenging, and is one in which industrial engineering methodology, applicable in dealing with large scale systems problems, has special relevance.

Another professional program of special interest is one leading to the Master of Business Administration (M.B.A.) degree offered by the Graduate School of Business and Public Administration, described in the Announcement of that School. By proper selection of elective courses and by completing the proper steps in admissions during the third year, the student may obtain the M.B.A. degree in one additional year beyond the B.S. program in contrast to the two additional years normally required for students in other engineering, science, or liberal arts programs.

The two professional programs mentioned above, plus the professional program in engineering (M.Eng.) and the research degree (M.S.), make four Master's degree programs readily available to qualified students who select the field of industrial engineering as their undergraduate area of concentration and, in two cases, the Master's degree can be earned in less time than if some other fields of concentration were chosen. In all cases where the student is contemplating graduate study, he should discuss this with his adviser and with the admissions officer of the unit in which he intends to do his graduate work, not later than the start of his sixth term at Cornell.

MATERIALS SCIENCE AND ENGINEERING

BARD HALL

Mr. W. S. Owen, Director; Mr. M. S. Burton, Assistant Director; Messrs. R. W. Balluffi, B. W. Batterman, J. M. Blakely, E. T. Cranch, T. R. Cuykendall, D. Dropkin, J. L. Gregg, D. F. Holcomb, J. P. Howe, J. O. Jeffrey, H. H. Johnson, J. A. Krumhansl, P. J. Leurgans, C. Y. Li, J. B. Newkirk, T. N. Rhodin, A. L. Ruoff, H. S. Sack, E. Scala, B. M. Siegel, M. J. Sienko, J. Silcox, F. O. Slate, G. V. Smith, R. L. Sproull, A. Taylor, R. L. VonBerg, W. W. Webb, C. C. Winding, G. Winter, G. J. Wolga.

Materials science is a new discipline which relates the principles of physics and chemistry to materials, while materials engineering has developed during the past several years principally from metallurgical engineering. This evolution has been hastened by rapid and extensive developments in non-metallic materials. Modern engineering requires new and improved materials having properties well beyond those attainable with common metals and alloys. Thus, further understanding of the nature of materials and control of their properties has become a vital factor in the development and selection of materials. Empirical approaches have been replaced by theoretical and analytical treatments of materials and their properties, as the art of metallurgy has become the science of materials. Selection, processing, and application of materials for specific needs has become the field of materials engineering.

Success of a system, a design, or a theory is realized only when the scheme has been translated by the materials and metallurgical engineer into a tried and tested engine, transistor, or missile. Development, selection, and fabrication of materials is the key to successful design, and even a modest improvement of a product is often contingent upon success in materials research, development, and engineering.

The materials and metallurgical engineer must be effectively educated to understand both the behavior and application of materials. Increasing complexity in chemical, mechanical, electrical, and aerodynamic applications of materials and their overlap, make full understanding of the basic behavior of the material in the proposed environment or system, a requisite of modern engineering. This is the field of materials science and engineering.

Laboratory and Research Facilities

The Materials Science and Engineering Department is centered in Bard Hall, and, in addition, occupies portions of Thurston Hall and Kimball Hall, a total area of 50,000 square feet. Facilities include the newest of the Cornell engineering buildings, Bard Hall, completed in 1963, and extensively equipped for both undergraduate and graduate instruction and research. New facilities for studying the structure of solids by physical measurements, microscopy, metallography, and x-ray diffraction are available. Equipment for processing materials by casting, welding, heat treatment, compacting and sintering, deformation, and for many of the newer processing procedures are included. Laboratories for preparing and studying non-metallic materials, especially ceramics, are also housed in Bard Hall.

This Department participates with other departments of the University in the interdisciplinary Materials Science Center established at Cornell with funds from the Advanced Research Projects Agency. The Materials Science Center supports central facilities in Bard and Thurston Halls for service and research in metallography, x-ray diffraction, effects of high temperature on materials, effects of high pressure on materials; and service facilities for producing, characterizing, and testing various metallic and non-metallic materials.

The Degree Programs

At Cornell, the materials science and engineering curriculum provides mathematics, physics, chemistry, and engineering sciences that are fundamental to effective work in materials science and materials engineering. Additional courses in the production of materials, structure of materials, relation of structure to properties, and processing of materials into required shapes having suitable structure and properties, relate fundamental sciences to metallurgy and materials. These, coupled with elective choices, allow the student to extend his education by specialized study in both materials science and materials engineering. Able students are encouraged to take at least one year of graduate study to extend their engineering course work, and their experience in laboratory investigation and research.

BACHELOR OF SCIENCE

Course program for Terms 1–4, administered by the Division of Basic Studies, are described on pages 31–32.

		Contact Hours	
	Credit Hours	*Lect. Rec.*	*Lab. Comp.*
TERM 5			
Engineering 6311, Materials Science	4	3	2½
Engineering 6301, Structure of Materials I	3	2	2½
Engineering 8121, Classical Thermodynamics	3	3	0
Free Elective	3	–	–
Liberal Elective	3–4	–	–
TERM 6			
Engineering 6312, Materials Science	3	3	0
Engineering 6302, Structure of Materials II	3	2	2½
Engineering 6423, Thermodynamics	3	3	0
Free Elective	6	–	–
Liberal Elective	3	–	–

	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
TERM 7			
Engineering 6435, Physical Metallurgy	4	4	0
Engineering 6443, Materials Processing	4	3	2½
Engineering 6524, Kinetics of Reactions in Solids	3	3	0
Free Elective	3	–	–
Liberal Elective	3–4	–	–
TERM 8			
Engineering 6432, Mechanical Metallurgy	3	3	0
Engineering 6442, Materials Processing (Chemical)	4	3	2½
Free Elective	6–7	–	–
Liberal Elective	3–4	–	–

Elective Courses

The program in materials science and engineering has 31 elective hours during the last two years, or nearly 45 percent of the curriculum. This flexibility allows students having special interests, either within the field or in other divisions of the College or University, to plan educational programs that closely parallel their interests. Faculty advisers of the Department will assist each student to plan a suitable program and to select appropriate elective courses.

The following are given as examples of elective groupings. Many others are possible.

MATERIALS SCIENCE

Chemistry 410, Inorganic Chemistry
Chemistry 481, Advanced Physical Chemistry
Chemistry 505, Advanced Inorganic Chemistry
Chemistry 506, Advanced Inorganic Chemistry
Physics 443, Atomic Physics and Introduction to Quantum Mechanics
Physics 454, Electronic Properties of Solids and Liquids

MATERIALS ENGINEERING

Engineering 6661, Metals at Elevated Temperatures
Engineering 6665, Materials for Spacecraft and Missiles
Engineering 6669, Introductory Physical Ceramics
Engineering 6872, Nuclear Materials Technology
Engineering 3331, Kinematics and Components of Machines
Engineering 3372, Experimental Methods in Machine Design
Engineering 1159, Experimental Mechanics
Engineering 1163, Applied Elasticity
Engineering 1168, Theory of Plasticity

NUCLEAR ENGINEERING

Engineering 8302, Nuclear and Reactor Physics
Engineering 8351, Nuclear Measurements Laboratory
Engineering 5760, Nuclear and Reactor Engineering
Engineering 3665, Advanced Heat Transfer
Engineering 6872, Nuclear Materials Technology

POLYMERIC MATERIALS

Chemistry 357, Introductory Organic Chemistry
Chemistry 358, Introductory Organic Chemistry
Engineering 5743, Polymeric Materials
Engineering 5752, Polymeric Materials Laboratory

The College Program

For students wishing to combine materials study with some other discipline, course sequences are available to provide a major or minor program in materials science and engineering. All students will be required to take Engineering 6311, Materials Science; and Engineering 6301, Structural Examination of Materials. Additional courses in materials science or materials engineering will complete the major or minor sequence. These will be selected to meet the needs of each student.

MASTER OF ENGINEERING (METALLURGY)

The Master of Engineering (Metallurgy) program, is open to students who have completed a four year undergraduate program in engineering or the physical sciences. The course of study can be completed in one academic year by students whose undergraduate training is in metallurgy, metallurgical engineering, or materials; one additional term is necessary for most students having other undergraduate preparation.

		Contact Hours	
	Credit	*Lect.*	*Lab.*
TERM 9	*Hours*	*Rec.*	*Comp.*
Engineering 6551, Production of Metals and Ceramics	3	3	0
Engineering 6553, Project	3	0	9
Engineering 6503, Service Behavior of Metals	3	3	0
Technical Elective	3	–	–
* Graduate Core Course	3	–	–
TERM 10			
Engineering 6552, Materials Engineering	3	3	0
Engineering 6554, Project	3	0	9
Technical Elective	6	–	–
* Graduate Core Course	3	–	–

* Selected from courses 6601, 6602, 6603, 6604, 6605, 6606.

Graduate Study

Unique opportunities are open to the student undertaking graduate study in materials at Cornell. Instruction is given in a broad spectrum of topics, ranging from the fundamental aspects of materials behavior to problems associated with materials applications in a multitude of engineering systems. Metallic and non-metallic materials, as well as some aspects of the liquid state, are incorporated into a common framework of instruction.

Graduate programs lead to the degrees of Master of Engineering (Metallurgy), Master of Science, and Doctor of Philosophy. The M.S. and Ph.D. programs are primarily science-oriented courses of study and research, which are directed toward a career in research, development, advanced engineering, or teaching. A candidate for either degree may choose as his major subject area either materials science or materials and metallurgical engineering.

The Field faculty usually requires that a student who enters with an undergraduate degree and desires to work toward the Ph.D. first register as a candidate for the M.S. Toward the end of his first year, the student's progress is reviewed by his Special Committee. If that group takes favorable action then, or at a later date, the student is recommended for admission to candidacy for the Ph.D. degree. If he wishes, the student may then proceed directly to the Ph.D. without taking the M.S. To form an adequate foundation for more specialized courses and for thesis research, the faculty has developed a core program of courses in materials science. These cover modern theories of materials behavior at an advanced level, including such topics as imperfections; nucleation theory; phase transformations; electric, magnetic, and mechanical properties of solids; lattice dynamics; phase equilibria; rate processes; etc.

Students interested in materials science may then proceed primarily with advanced courses in the basic sciences such as statistical mechanics, advanced solid state physics, theoretical chemistry, etc., while students interested in the technological aspects of materials and metallurgical engineering may proceed with such courses as high temperature materials, physical metallurgy of ferrous materials, powder metallurgy, nuclear materials technology, and others. Some students may wish to take various combinations of these two types of graduate courses.

The courses offered by the Field presume a sound undergraduate education in such areas as mathematics, physical metallurgy, atomic and solid state physics, and metallurgical thermodynamics. Entering graduate students with deficiencies in any of these areas will be permitted to remedy their deficiencies with intermediate level courses, with the understanding that somewhat more time may be needed to complete the degree program.

Finally, a significant part of the Cornell graduate educational experience is the opportunity to participate in formal and informal seminars and research conferences, where current Cornell research programs are described and guest speakers present the latest developments in other laboratories.

MECHANICAL ENGINEERING

UPSON HALL

Mr. G. R. Hanselman, Acting Director; Messrs. N. W. Abrahams, T. J. Baird, J. F. Barrows, J. F. Booker, A. H. Burr, B. J. Conta, D. Dropkin, G. B. DuBois, F. S. Erdman, H. N. Fairchild, B. Gebhart, R. L. Geer, J. O. Jeffrey, H. N. McManus, Jr., F. K. Moore, J. R. Moynihan, F. W. Ocvirk, R. M. Phelan, F. J. Pierce, D. G. Shepherd, R. L. Wehe.

Mechanical engineering is the broadest of the several fields of engineering, and the curriculum is designed to provide this breadth in training. To be useful to society, practically all engineering achievements must be finally reduced to mechanical form. Producing the end products and providing the industrial equipment are the provinces of the mechanical engineer.

The great advances made in the fields of engineering and the sciences since World War II have opened new horizons, and mechanical engineers are involved in creating new products for such exciting fields as space travel, underwater exploration, and computer technology, as well as the more established fields of energy conversion, transportation, and control. Materials handling, plant engineering, applications of nuclear power, industrial sales and management are frequently attractive to mechanical engineers.

The mechanical engineer works with scientists and engineers in other fields. It is usually the function of the mechanical engineer to take the device or system which has been proposed and proved in principle, design it into an assembly of real components, analyze and improve critical mechanical features, make cost analyses, and follow the parts through production. In other words, he designs and produces the actual components and ensures that the whole assembly functions as a system. Because of the broad spectrum of this field, the mechanical engineering student receives instruction in the technical areas not only from mechanical engineering professors but also from electrical, industrial, and metallurgical engineering professors.

The Sibley School of Mechanical Engineering consists of four departments of instruction:

Graphics and Industrial Design, T. J. Baird, 408 Upson Hall.
Machine Design, A. H. Burr, 306 Upson Hall.
Materials Processing, R. L. Geer, 220 Kimball Hall.
Thermal Engineering, D. G. Shepherd, 206 Upson Hall.

Laboratory and Research Facilities

Extensive, modern laboratories in each of these departments provide the student with the finest equipment for studying engineering principles. The thermal engineering and machine design laboratories are located in Upson Hall; materials processing laboratories are in Kimball Hall.

In the thermal engineering area, modern instrumentation and techniques are used for regular instruction in the steady and transient state measurement of temperature, heat flow and properties of flowing fluids. The laboratories are equipped with precision potentiometers, pressure transducers, oscilloscopes, oscillographs, hot-wire anemometers, etc. Considerable use is made of visualization equipment, such as shadowgraph and schlieren apparatus, flow models, and films. In several courses, the services of the Cornell Computing Center are employed as a necessary adjunct to modern mechanical engineering.

The Department of Machine Design has its own laboratories for stress, vibration, and endurance testing of machine parts as well as for the study of hydraulic and pneumatic controls. Numerous electronic instruments are available for the measurement and recording of force, motion, strain, vibration, and noise. The laboratories are particularly well equipped for studies of lubrication phenomena in journal bearings and for studies requiring the use of analog computers.

The materials processing laboratories, with a generous selection of production-type machine tools, provide undergraduate and research facilities for tool planning, statistical quality control, surface texture, and dynamometric projects. Specially tooled and instrumented equipment for studying tool wear and geometry characteristics, chip formation, work-tool temperature phenomena, and stress patterns is available. For metrology and gaging studies, a constant temperature room is available. The laboratories are well equipped with all standard-type measuring devices, including optical, electronic, and pneumatic comparators.

The Degree Programs

The undergraduate program in mechanical engineering leads to a Bachelor of Science (B.S.) degree upon the successful completion of a four-year curriculum.

The first two years of this program are given in the Division of Basic Studies and are substantially common to all undergraduate engineering students. In the sophomore year, two engineering science sequences are required. Students considering mechanical engineering for their major field should take the mechanics sequence, since it is a prerequisite for junior courses in this field.

In the junior and senior years, 54 credit hours of technical courses related to mechanical engineering are required. These include courses in the Mechanical Engineering Departments of Thermal Engineering, Machine Design, and Materials Processing plus specified courses in the Departments of Industrial Engineering and Operations Research and Materials Science and Engineering. In addition, 18 credit hours of both liberal and unrestricted electives are required.

A summary of the four-year requirements in these three categories — engineering, science, and English plus electives — appears in the following outline:

ENGINEERING COURSES

	Credit Hours
Problems and Methods	6
Engineering Mechanics	6
Electrical Science	6
Materials Science	6
Materials Engineering	3
Engineering Statistics	3
Thermal Science and Thermal Engineering	20
Materials Processing	3
Machine Design and Systems Design	13
	66

SCIENCE COURSES

Mathematics	15
Physics	12
Chemistry	6
	33

ENGLISH AND ELECTIVES

English	6
Liberal Electives	18
Technical Electives	6
Unrestricted Electives *	6
	36
Total	135

* Unrestricted Electives may be any courses in the University to which the student can gain admission, including 6 hours of Advanced ROTC.

Unrestricted and technical electives are taken in the fourth year. Careful consideration should be given to the choice of these courses, since they may be related to a subsequent graduate program.

Successful completion of the requirements for the B.S. degree will enable a student to continue his engineering education at the graduate level leading to the Master of Engineering (Mechanical) degree, the Master of Science (M.S.), or the Doctor of Philosophy (Ph.D) degree. (See sections on Graduate Study, pages 74 and 75.)

SCHOLASTIC REQUIREMENTS

A student in the School of Mechanical Engineering who fails in any term to earn a passing grade in fifteen hours, with a grade of 70 or better in eleven hours, may be placed on probation. If he fails in any term to pass twelve hours, he may be dropped from the School.

BACHELOR OF SCIENCE

TERMS 1–4

See Division of Basic Studies Curriculum, pages 31–32. Credit hours=63.

	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
TERM 5			
Engineering Science (Electrical or Materials)	3	2	2½
Engineering 3321, Kinematics and Dynamics of Mechanisms	3	2	2½
Engineering 3431, Materials Processing	3	1	5
Engineering 3621, Thermal Science I: Thermodynamics	3	3	0
Engineering 6316, Materials Engineering	3	2	2½
Liberal Elective *	3	–	–
Total	18		
TERM 6			
Engineering Science (Electrical or Materials)	3	2	2½
Engineering 3322, Analysis and Design of Machine Components	3	2	2½
Engineering 3622, Thermal Science II: Thermodynamics	2	2	0
Engineering 3623, Thermal Science III: Fluid Mechanics	4	4	0
Engineering 9170, Industrial and Engineering Statistics	3	2	2½
Liberal Elective *	3	–	–
Total	18		
TERM 7			
Engineering 3053, Mechanical Engineering Laboratory	4	1	5
Engineering 3324, Vibration and Control of Mechanical Systems	3	2	2½
Engineering 3625, Thermal Science V: Heat Transfer	3	3	0
Liberal Elective *	3	–	–
Unrestricted Elective †	3	–	–
Technical Elective	3	–	–
Total	19		

TERM 8	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
Engineering 3054, Design of Mechanical Engineering Systems	4	2	5
Engineering 3626, Thermal Systems Engineering	4	2	2½
Liberal Elective *	3	–	–
Unrestricted Elective †	3	–	–
Technical Elective	3	–	–
Total	17		
Total for eight terms	135		

* See page 33 for definition of liberal electives.
† See footnote on page 33 for definition of unrestricted electives.

MASTER OF ENGINEERING (MECHANICAL)

The degree of Master of Engineering (Mechanical) is available as a curriculum type of professional degree, the general requirements for which are stated on page 22. Specialized programs leading to this degree may be undertaken in the area of Machine Design including machine dynamics and control, mechanical analysis and development, mechanical design, and vehicles and propulsion; in the area of Thermal Engineering including heat transfer and fluid dynamics, nuclear technology, propulsion engines, thermal environment, and thermal power; and in the area of Materials Processing including manufacturing engineering, material removal, and metrology and gaging.

The professional degree, M.Eng.(Mechanical), may be earned in a minimum of two terms of full-time study by the successful completion of the requirements described below (see also the comments that follow).

FALL TERM	Credit Hours
Mathematics	3
Engineering 3361, Advanced Mechanical Analysis	3
Engineering 3651, Advanced Thermal Science	3
Engineering Laboratory	3
Technical Elective	3
Total	15

SPRING TERM	
Mathematics	3
Engineering 3055, Advanced Mechanical Engineering Design	3
Engineering 3090, Mechanical Engineering Design Project	3
Mechanical Engineering Elective	3
Technical Elective	3
Total	15
Total for two terms	30

In the curriculum outlined above, the *mathematics requirement* may be satisfied by Mathematics 315, 316, or Applied Mathematics 1180. 1181, or other approved courses. The *Engineering Laboratory* course in the fall term may be selected from Experimental Methods in Machine Design, 3372, Advanced Thermal Engineering Measurements I, 3667, or Advanced Thermal Engineering Measurements II, 3673. Mechanical Engineering Design Project, 3090, in the spring term, provides design experience requiring individual effort and the preparation of a formal report. The last 6 hours of the fall term and the last 9 hours listed under the spring term offer varying degrees of choice as to specific courses. Thus, the program has a built-in feature of 15 hours which may be devoted to a particular area of concentration of greatest interest to the student. Furthermore, if the six-hour mathematics requirement is previously satisfied when fulfilling undergraduate elective requirements, six additional hours can be used for this purpose to bring the total available to 21 credit hours.

MASTER OF ENGINEERING (MECHANICAL), M.S., AND PH.D DEGREES

Graduate education in engineering becomes more and more desirable each year to gain adequate preparation for careers in engineering practice, research, or teaching. Graduate programs are available in mechanical engineering leading to the degrees of Master of Engineering (Mechanical), Master of Science, and Doctor of Philosophy.

The regulations and requirements for the degrees of Master of Science and Doctor of Philosophy are described in the *Announcement of the Graduate School.* These are research degrees that involve residence on the campus and submission of a thesis.

A prospective candidate for one of the advanced degrees should consult *Graduate Engineering at Cornell University.*

AGRICULTURAL ENGINEERING

RILEY-ROBB HALL

Mr. O. C. French, Director; Messrs. R. D. Black, W. W. Gunkel, R. B. Furry, G. Levine, R. T. Lorenzen, D. C. Ludington, W. F. Millier, N. R. Scott, E. S. Shepardson, J. C. Siemens, J. W. Spencer.

A joint program administered by the Colleges of Agriculture and Engineering leads to the degree of Bachelor of Science. Students in this curriculum register in the College of Agriculture during the first three years but take courses in the Colleges of Engineering, Arts and Sciences, and Agriculture. Registration for the fourth and final year is in the College of Engineering, which grants the degree.

The purpose of this curriculum is to prepare engineers for a career in one of the many industries and agencies that supply the great variety of products, machines, and services required by commercial farms, or those which process, handle, and distribute the products from farms.

Agricultural engineers are in great demand for design, research, development, and marketing of machines, structures, and systems that are vital for modern agricultural production.

Riley-Robb Hall with over 100,000 square feet of floor area provides excellent classroom and laboratory facilities for both teaching and research. Major items of laboratory equipment includes electric dynamometers, universal testing machines, fluid flow demonstration and metering equipment, strain measurement instruments, digital recording equipment, torque meters, high speed camera and film analysis equipment, modern farm machines, power units and materials handling equipment, soil properties and moisture determination apparatus, and complete machine shop facilities.

The department has an extensive research program supported through the Cornell Agricultural Experiment Station which provides many students with opportunities for part-time work during the academic year and summer periods.

Practice Requirement

Since agricultural engineering students are registered in the College of Agriculture for the first three years, they must meet the practice requirement of that College. The basic requirement is 25 units of acceptable farm experience gained at the approximate rate of one unit per week. Twelve of these units must be completed before registration for the sophomore year. The entire 25 units must be completed prior to registration in the third year. *The Announcement of the College of Agriculture* should be consulted for details of the requirement.

Scholastic Requirements

To remain in good standing, a student must have a weighted average for the term of 70 or above. If the weighted average is 60 or higher, but less than 70, the student will be placed on probation. A student will be dropped from the program if a third consecutive term of probation is indicated or if the weighted average is below 60. In all cases, the student may appeal an action to the Joint Faculty Committee.

The Degree Program

BACHELOR OF SCIENCE

(For a complete description of the courses in agriculture, consult the *Announcement of the College of Agriculture.)*

		Contact Hours	
	Credit Hours	*Lect. Rec.*	*Lab. Comp.*
TERM 1			
Mathematics 191, Calculus for Engineers	4	4	0
Physics 121, Introductory Analytical Physics	3	3	2½
Chemistry 103, General Chemistry	3	3	2½
English 111, Introduction to English	3	3	0
Agr. Engineering 153, Engineering Drawing	3	2	3½
Agriculture 101, Orientation	1	1	0
Total	17		
TERM 2			
Mathematics 192, Calculus for Engineers	4	4	0
Physics 122, Introductory Analytical Physics	3	3	2½
Chemistry 104, General Chemistry	3	3	2½
English 112, Introduction to English	3	3	0
Agr. Engineering 151, Introduction to Agr. Engr.	3	1	3½
Total	16		

In addition to these courses, all freshmen must satisfy the University's requirements in physical education.

TERM 3			
Mathematics 293, Engineering Mathematics	4	4	0
Physics 223, Introductory Analytical Physics	4	3	2½
Engineering 211, Mechanics of Rigid and Deformable Bodies	4	3	2½
Biology 101, General Biology	3	2	2½
Chemistry 276, Introduction to Physical Chemistry	3	3	0
Total	18		
TERM 4			
Mathematics 294, Engineering Mathematics	3	3	0
Physics 224, Introductory Analytical Physics	4	3	2½
Engineering 212, Mechanics of Rigid and Deformable Bodies	4	3	2½
Engineering 6311, Materials Science	4	3	2½
Biology 102, General Biology	3	2	2½
Total	18		

In addition to these courses, all sophomores must satisfy the University's requirements in physical education.

	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
TERM 5			
Engineering 3621, Thermal Science	3	3	0
Agronomy 111, Field Crops	4	3	2½
Engineering 2701, Structural Theory	3	2	2
Extension Teaching 301, Speech	2	–	–
Electives	6	–	–
Total	18		
TERM 6			
Engineering 3622, Thermal Science (2 hr) or 2301, Fluid Mechanics (3 hr)	2 or 3	3	0
Agronomy 200, Nature and Properties of Soils	4	3	2½
Agr. Engineering 481, Agr. Structures	3	2	2½
Engineering 3321, Kinematics	3	2	2½
Electives	6	–	–
Total	18 or 19		
TERM 7			
Engineering 2301, Fluid Mechanics (3 hr) or 2303, Hydrology (2 hr) *	2 or 3	3	0
Animal Husbandry 100 or 250	3	2	2½
Electrical Engineering I	3	2	2½
Agr. Engineering 461, Agr. Machinery Design	3	2	2½
Electives	6	–	–
Total	17 or 18		
TERM 8			
Agr. Engineering 462, Agr. Power	3	2	2½
Agr. Economics 302, Farm Management	5	3	2½
Agr. Engineering 471, Soils and Water Engr.	3	3	2½
Electrical Engineering II	3	2	2½
Electives	3	–	–
Agr. Engineering 450, Spec. Topics	1	1	0
Total	18		
Total for eight terms	140–142		

* Students selecting more specialization in soils and water engineering would elect a sequence of Thermal Science 3621, Fluid Mechanics 2301, and Hydrology 2303. Others would elect a sequence of Thermal Science 3621, 3622 and Fluid Mechanics 2301.

MASTER OF ENGINEERING (AGRICULTURAL)

The following are entrance requirements for the curriculum:

1. Baccalaureate degree in engineering.
2. A minimum of (a) 6 semester hours in biological science; (b) 12 semester hours in agricultural engineering; (c) 12 semester hours in the areas of soil science, plant science, animal science, agricultural economics.
3. A cumulative average of 75 in the undergraduate program.

FALL TERM

	Hrs.
Agr. Eng. 463, Processing & Materials Handling Systems	4
Agr. Eng. 451, Design Project	3
Agr. Eng. Electives	6
Engineering Electives	3
Total	16

SPRING TERM

Agr. Eng. 452, Design Project	3
Agr. Eng. Electives	6
Engineering Electives	6
Total	15

Agricultural engineering electives will be selected to provide depth of preparation in one of the following areas: (a) power and machinery, (b) soils and water, and (c) agricultural structures and associated systems.

Engineering electives are to be chosen from subject areas relevant to agricultural engineering such as thermal engineering, mechanical design and analysis, theoretical and applied mechanics, structural engineering, hydraulics, soils engineering.

M.S. AND PH.D DEGREES

Flexible programs leading to both the M.S. and Ph.D. are offered in the following areas of specialization for either a major or minor: agricultural structures, power and machinery, soil and water engineering, and electric power and processing. Minors for those majoring in agricultural engineering may be selected from the engineering, agricultural, or basic sciences. A broad and active research program, supported by the Cornell Agricultural Experiment Station, gives the student an opportunity to select a challenging research project for his thesis. Several assistantships are available with annual stipends that are comparable to those offered at other Land Grant institutions. For more detailed information write the Graduate Field Representative, Riley-Robb Hall, Cornell University.

AEROSPACE ENGINEERING (GRADUATE PROGRAM)

GRUMMAN HALL

Mr. E. L. Resler, Jr., Director; Messrs. J. M. Burgers, P. T. deBoer, A. R. George, I. Imai, J. W. Linnett, W. R. Sears, A. R. Seebass III, S. F. Shen, D. L. Turcotte.

Aerospace engineering is the field of engineering that deals with problems concerned with the flight of aircraft, guided missiles, and space vehicles in planetary atmospheres and in the regions of space adjoining these atmospheres. The primary objective of this School is to educate selected engineering and science graduates in the research and technical aspects of this field. The training is intended especially to prepare students for research and development engineering in the aerospace industry and in allied research institutions, and for university teaching and reserach.

Superior facilities are provided for laboratory studies in fluid mechanics, aerodynamics, gasdynamics, plasma physics, high temperature chemical kinetics, rarefied gas dynamics, magnetohydrodynamics, and other areas. Students and staff also carry out highly theoretical investigations in such subjects of their own choice in the aerospace field or in subjects related to the above experimental areas. Emphasis is put upon the scientific and engineering aspects of the phenomena encountered by space vehicles which leave and re-enter planetary atmospheres at extreme speeds. Research work may also be carried out in other related disciplines of mutual interest to the student and advising professors.

Preparation for Graduate Study

The Graduate School of Aerospace Engineering will admit students holding baccalaureate degrees in any branch of engineering, mathematics, or the physical sciences from qualified institutions, provided that their undergraduate scholastic records are such as to indicate ability to handle graduate study. The Cornell courses of study in engineering physics, electrical engineering, and mechanical engineering are especially recommended to students who expect to enter this School after graduation.

All students who expect to enter the Graduate School of Aerospace Engineering should try to arrange their undergraduate programs to include as much work as possible in applied mechanics, thermodynamics, mathematical analysis, chemistry, and physics. Suggested courses for engineering students to elect as preparation for graduate work in aerospace engineering include areas of intermediate or advanced physics, such as atomic and molecular physics, kinetic theory of gases, electricity and magnetism, etc.

The Degree Programs

MASTER OF ENGINEERING (AEROSPACE)

Undergraduate students who have demonstrated more than average ability, have shown adequate promise for carrying on graduate study and are interested in extending their education in the aerospace field by training in advanced analytical and research-oriented aerospace subjects are eligible to apply for this program.

Applications for admission should be made to the Director of the Graduate School of Aerospace Engineering, Grumman Hall, Cornell University. A special application blank for this purpose can be obtained from the Director's office. It should be returned directly to him.

The program of aerospace engineering studies is designed to acquaint the student with pioneering engineering work in the aerospace industry, and beyond that its objective is to increase the student's facility in the use of the basic sciences in engineering and to stimulate his growth in independent research and development work. Because progress in this field is so rapid, an essential objective of this program is to go beyond the study of present-day practices and techniques and to supply the student with a fundamental background and analytical techniques that generally will prove useful whatever the direction of modern engineering development.

The successful completion of the work for this degree requires that the student pass a series of courses or examinations in the subjects listed below. The subject list constitutes a standard of accomplishment for the M.Eng. (Aerospace) candidate, but the faculty may modify the list to suit the needs, interests, and background of each individual candidate. Courses are currently available to permit candidates to study in any of four areas of aerospace engineering: (1) fluid mechanics; (2) high temperature gasdynamics; (3) magnetohydrodynamics; and (4) space mechanics. Active research in these areas is being carried out in the School. Other course sequences leading to specialization in allied fields can also be arranged, for example, aerospace structures, aerophysics, chemical kinetics, etc. Faculty members and visiting staff frequently offer additional courses (to those listed on pages 151–153) in their specialty.

The M.Eng. (Aerospace) is awarded for course work only and requires successful completion of two six-hour sequences from those listed below, six hours of mathematics (1180–81, or 415–416, or equivalent), six hours of electives, attendance at the weekly colloquium, and one advanced seminar (two hours) each term. This is a total of 30 credit hours. Exceptions in rare instances may be made at the discretion of the faculty. "Successful completion" of the course sequences is interpreted as a 75 average in course work.

Course Sequences Available for M.Eng.(Aerospace)

	Hours
Engineering 7101–02, Advanced Kinetic Theory, Gasdynamics	6
Engineering 7201–02, Magnetohydrodynamics I and II	6
Engineering 7301–02, Fluid Mechanics I and II	6
Engineering 1171, 1172, Artificial Satellite Theory, Space Flight Mechanics	6

Electives: List A *

7103, Dynamics of Rarefied Gases	3
7104, Advanced Topics in High Temperature Gasdynamics	3
7203, Advanced Topics in Magnetohydrodynamics	3
7303, Fluid Mechanics III	3
7304, Theory of Viscous Flows	3
7305, Hypersonic Flow Theory	3

* Basic sequence (01–02) or equivalent is required for registration in elective courses in list A.

Electives: List B

	Hours
1162, Theory of Vibration	3
1163, Applied Elasticity	3
1164, Theory of Elasticity I	3
1165, Theory of Elasticity II	3
1167, Theory of Plate and Shell Structures	3
1170, Advanced Dynamics	3
1175, Oscillations in Nonlinear Mechanics	3
3652, Combustion Theory	3
3674, Microscopic Thermodynamics	3
Physics 443, Atomic Physics and Introduction to Quantum Mechanics	3
Physics 444, Nuclear and High Energy Particle Physics	3
Physics 454, Electronic Properties of Solids and Liquids	3
Physics 510, Advanced Experimental Physics	3
Physics 561, Classical Theoretical Physics I	4
Physics 562, Classical Theoretical Physics II	4
Physics 573, Electrodynamics	3
Physics 572, Quantum Mechanics	3
Physics 574, Intermediate Quantum Mechanics	3
Chemistry 580, Kinetics of Chemical Reactions	3
Chemistry 593, Introduction to Quantum Mechanics	3
Chemistry 595, Statistical Mechanics	3
Chemistry 598, Molecular Spectra	3
EE 4531, Quantum Electronics I	3
EE 4532, Quantum Electronics II	3
EE 4561, Plasma Physics I	3
EE 4562, Plasma Physics II	3
EE 4661, Kinetic Equations	3
EE 4662, Kinetic Theory of Plasmas	3

M.S. AND PH.D. DEGREES

To do original work in aerospace engineering in its broadest sense requires further advanced study in the graduate field, plus a thesis. Such study may lead to the degrees of Master of Science or Doctor of Philosophy. The student usually works very closely with the faculty members of the School in fields such as basic plasma dynamics, high temperature chemical reactions, space mechanics problems, fundamental fluid mechanics, etc. The programs are extremely broad in order to accommodate the widest interests of the students and the broadest needs of the industry.

The School's activities are best summarized through its research work and papers. Those interested in obtaining copies or abstracts of work recently completed may obtain them by writing to the Director of the School, Grumman Hall.

THEORETICAL AND APPLIED MECHANICS

THURSTON HALL

Mr. J. R. Moynihan, Acting Director; Messrs. P. P. Bijlaard, H. D. Block, H. D. Conway, E. T. Cranch, M. D. Greenberg, R. H. Lance, G. S. S. Ludford, T. P. Mitchell, J. P. Moran, Y. H. Pao.

The Department of Theoretical and Applied Mechanics is responsible for undergraduate and graduate instruction and research in theoretical and applied mechanics and applied mathematics. Subject matter in these fields is of a fundamental nature, and the undergraduate courses provide a substantial part of the basic engineering science education for engineering students. In addition to the required courses in theroetical and applied mechanics and applied mathematics, the undergraduate can elect advanced courses. Such courses are especially suited to students who have demonstrated superior analytical or experimental ability and who wish to extend and develop this ability. The Department will offer major and minor individualized planned programs in the newly initiated College Program (see page 17).

The graduate program in mechanics and applied mathematics emphasizes fundamental understanding of the newest developments in engineering and applied science. Graduate students are exposed to the mechanics of liquids, gases, particles, rigid and deformable solids and related areas of materials, mathematics, and physics. The analytical nature of the studies encourages research that cuts across various fields. Graduate students pursue programs in the following areas of specialization: (1) space mechanics — including research on trajectories and orbits of space vehicles and satellites as well as the theory of light-weight, thin-walled structures; (2) wave propagation in solids — with research on the dynamic response of plates, structures, and machine elements; (3) structural mechanics including static and dynamic loading, vibrations, and buckling; (4) theory of elasticity and plasticity; (5) theoretical fluid mechanics — with research in magnetohydrodynamics.

The flexibility of the graduate study programs at Cornell permits students to draw on several divisions of the University for supporting work in pure and applied science. Graduate students interested primarily in theoretical and applied mechanics and applied mathematics find these supporting fields of interest: mathematics, structures, engineering physics, servomechanisms, machine design, aerospace engineering, soil mechanics, and physics.

DESCRIPTION OF COURSES

The courses listed in the preceding curricula are described in the sections following. Courses are described under the heading of the school, department, or division in which they are offered. Courses in chemistry, English, mathematics, and physics, and certain courses in economics are offered by the College of Arts and Sciences.

Courses offered by the Division of Basic Studies in the College of Engineering have three digit numbers. Courses listed under the intercollege division of Computer Science also have three digit numbers and follow the Basic Studies listings. All other courses offered within the College have four digit numbers, the first digit representing the school or department. Descriptions of courses will be found in the section of this Announcement as follows:

1. Theoretical and Applied Mechanics
2. Civil Engineering
3. Mechanical Engineering
4. Electrical Engineering
5. Chemical Engineering
6. Materials and Metallurgy
7. Aerospace Engineering
8. Engineering Physics
9. Industrial Engineering and Operations Research

For courses in other colleges not described here, to be taken either as required courses or as electives, see the Announcement of the appropriate college.

DIVISION OF BASIC STUDIES

Engineering Problems and Methods

103. ENGINEERING GRAPHICS AND DESIGN

Credit 3 hrs. Either term. 1 Lect., 1 Rec., 1 Lab. Fundamentals of the engineering graphic language including orthographic drawing and sketching, pictorial drawing and sketching, auxiliaries, sections, intersections, and developments. Instrument drawings will show applications of visual communication in the design process. Freehand conceptual design.

104. ENGINEERING PROBLEMS AND METHODS

Credit 3 hrs. Either term. 1 Lect., 1 Rec., 1 Problem period. Consideraion of functions of engineering and major examples of modern engineering to emphasize the nature of engineering and the interrelationships of the several professional fields. Introduction to professional methods in solution of engineering problems and modern digital computation by machine methods.

Mathematics

191. CALCULUS FOR ENGINEERS

Credit 4 hrs. Either term. 2 Lect., plus recitation periods to be arranged. Preliminary examinations will be held at 7 p.m. on Oct. 20, Nov. 10, Dec. 8, Jan. 12.

Plane analytic geometry, differential and integral calculus, applications. Messrs. Kiefer and Kochen.

192. CALCULUS FOR ENGINEERS

Credit 4 hrs. Either term. Prerequisite, 191. 2 Lectures, plus recitation periods to be arranged. Preliminary examinations will be held at 7 p.m. on Mar. 2, Mar. 23, Apr. 20, May 18.

Transcendental functions, technique of integration and multiple integrals, vector calculus, analytic geometry in space, partial differentiation, applications. Messrs. Gershenson and Williamson.

293. ENGINEERING MATHEMATICS

Credit 4 hrs. Either term. Prerequisite, 192. 2 Lect., plus recitation periods to be arranged. Preliminary examinations will be held at 7 p.m. on Oct. 19, Nov. 30, Jan. 11.

Vectors and matrices, first order differential equations, infinite series, complex numbers, applications. Problems for programming and running on the automatic computer will be assigned, and students are expected to have a knowledge of computer programming equivalent to that taught in Engineering 102. Messrs. Robertson and Walker.

294. ENGINEERING MATHEMATICS

Credit 3 hrs. Either term. Prerequisite, 293. 2 Lect., plus recitation periods to be arranged. Preliminary examinations will be held at 7 p.m. on Mar. 15, Apr. 19, May 17.

Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, applications. Messrs. Hilton and Walker.

Physics

121–122. INTRODUCTORY ANALYTICAL PHYSICS

Credit 3 hrs. a term. Throughout the year. (Physics 121 is also offered in the spring term for students who have completed but failed the course in the preceding fall term; permission of the instructor is required.) Prerequisite, calculus or co-registration in Math. 191–192. Course 121 is prerequisite to 122. Primarily for students of engineering. 1 Lecture, two discussion periods per week and one 2½ hour laboratory period every other week, as assigned. Preliminary examinations will be held at 7:30 p.m. on Oct. 26, Nov. 30, Jan. 11, Mar. 15, Apr. 12, May 17.

The mechanics of particles: kinematics of translation, dynamics, conservation of energy. The properties of the fundamental forces: gravitational, electromagnetic, and nuclear. Conservation of linear momentum, kinetic-molecular theory of gases, properties of solids and liquids, mechanics of rigid bodies, harmonic motion. At the level of *Introductory Analytical Physics,* third edition, by Newhall. Messrs. Newhall, Gross, Kuo, and Staff.

223–224. INTRODUCTORY ANALYTICAL PHYSICS

Credit 4 hrs. a term. Throughout the year. (Physics 223 is also offered in the spring term for students who have completed but failed the course in the preceding fall term; permission of the instructor is required.) Prerequisites, Physics 122 and co-registration in Math. 293–294, or equivalent. Course 223 is prerequisite to 224. 1 Lecture, two discussion periods and one 2½ hour laboratory period every week, as assigned.

A survey of electric and magnetic fields including a review and an extension of the study of static fields and their sources. Fields in simple dielectrics, charges in motion, time-varying fields, induced electromotance, fields in magnetic materials, energy of charge and current distributions, electrical oscillations, electromagnetic field relations. Wave motion with emphasis on the properties of electromagnetic waves; reflection, refraction, dispersion, and polarization. Superposition of waves; interference and diffraction. Selected topics from contemporary physics such as relativity, quantum effects, atomic and x-ray spectra, nuclear structure and reactions, solid state physics. The laboratory work includes experiments in electrical measurements, physical electronics, optics, and nuclear physics. At the level of *Electric and Magnetic Fields* by Tomboulian and of *Elementary Modern Physics* by Weidner and Sells. Messrs. Talman, Peterson, K. Wilson, and Staff.

225–226. INTRODUCTORY ANALYTICAL PHYSICS

Credit 4 hrs. a term. Throughout the year. Prerequisite, same as for Physics 223–224. Course 225 is prerequisite to 226. 1 Lecture, two discussion periods and one 2½ hour laboratory period every week, as assigned.

The main topics are the same (none omitted) as those listed under Physics 223–224, but their treatment is more analytical and somewhat more intensive. At the level of *Electricity and Magnetism* by Kip, *Optics* by Rossi, and *Elementary Modern Physics* by Weidner and Sells. Messrs. Delvaille, Fitchen, and Staff.

Chemistry

103–104. INTRODUCTION TO CHEMISTRY

Credit 3 hrs. a term. Throughout the year. Chemistry 103 is prerequisite to Chemistry 104. Recommended for students who have not had high school chemistry and for those desiring a more elementary course than Chemistry 107–108. If passed with a grade of 70, this course serves as prerequisite for Chemistry 205 or Chemistry 353. 2 Lectures, and combined three-hour discussion-laboratory period.

An introduction to chemistry with emphasis on the important principles and facts of inorganic and organic chemistry. Messrs. Burnham, Freed, Porter, and Assistants.

Note: Entering students exceptionally well prepared in chemistry may receive advanced credit for Chemistry 103–104 by demonstrating competence in the Advanced Placement examination of the College Entrance Examination Board, or in the advanced standing examination given at Cornell on the Tuesday before classes start in the fall. Application for this latter examination should be made to the Department of Chemistry no later than registration day.

107–108. GENERAL CHEMISTRY

Credit 3 hrs. fall term and 4 hrs. spring term. Througout the year. Prerequisite, high school chemistry; 107 is prerequisite to 108. Recommended for those students who will take further courses in chemistry but do not intend to specialize in chemistry or closely related fields. 2 Lectures and combined three-hour discussion-laboratory period. In spring term, one additional recitation hour as arranged. Scheduled preliminary examinations may be held in the evenings.

The important chemical principles and facts are covered, with considerable attention given to the quantitative aspects and to the techniques which are important for further work in chemistry. Second-term laboratory includes a simplified scheme of qualitative analysis. Messrs. Plane, Sienko and Assistants.

115–116. GENERAL CHEMISTRY AND INORGANIC QUALITATIVE ANALYSIS

Credit 4 hrs. a term. Throughout the year. Prerequisite, high school chemistry at a grade of 85 or higher; Chemistry 115 is prerequisite to Chemistry 116. Recommended for students who intend to specialize in chemistry or in closely related fields. Students without good mathematical competence are advised not to take this course. Fall term three lectures and one three-hour combined discussion-laboratory period. Spring term: two Lectures, and two 3-hour combinded discussion-laboratory periods.

A general study of the laws and concepts of chemistry based upon the more common elements, and application of the theory of chemical equilibrium to the properties and reactions of ions of the common elements and their separation and detection in solution. Mr. Laubengayer and Assistants.

276. INTRODUCTION TO PHYSICAL CHEMISTRY

Credit 3 hours. Fall term. Prerequisites, Chemistry 104 or 108 or 116, Mathematics 192, and Physics 122. For engineering students. Examinations, Th 7:30 p.m.

A brief survey of physical chemistry. Mr. Albrecht.

285–286. INTRODUCTORY PHYSICAL CHEMISTRY

Credit 5 hrs. a term. Throughout the year. Prerequisites, Chemistry 108 or 116, Mathematics 192, Physics 123, or consent of instructor. Three lectures, 1 laboratory lecture, and 2 laboratories.

The lectures will give a systematic treatment of the fundamental principles of physical chemistry. The laboratory will deal with the experimental aspects of the subject and also develop the needed skills in quantitative chemical analysis. Messrs. Hughes, Lind and Assistants.

English

111–112. INTRODUCTION TO ENGLISH

Credit 3 hrs. a term. Throughout the year. English 111 is prerequisite to English 112.

Practice in writing. Careful study of works by a small number of selected modern writers. Mr. McConkey and others.

Physical Education

All undergraduate students are required by the University to complete four terms of work in physical education. The requirement must be completed within the first four terms (for further details, see the *Announcement of General Information*). Descriptions of the physical education courses offered will be found in publications made available to entering students by the Department of Physical Education and Athletics.

Electrical Science

241. ELECTRICAL SCIENCE I

Credit 3 hrs. Fall-Spring. 2 Lect., 1 (2½-hour) Rec.-Comp. Prerequisites, Math. 192 and Physics 122 and co-registration in Math. 293 and Physics 223. The basic principles of electric and magnetic fields and circuits for steady fields, voltages, and currents. Emphasis is placed on understanding of the physical concepts.

242. ELECTRICAL SCIENCE II

Credit 3 hrs. Spring-Summer. 2 Lect., 1 (2½-hour) Rec.-Comp. Prerequisites, Elec. Sci. 241, Math. 293, and Physics 223 and co-registration in Math. 294 and Physics 224. Extends the treatment of 241 to time-varying fields, voltages, and currents. The relaxation and steady-state behavior of simple systems.

243. ELECTRICAL SCIENCE I

Credit 3 hrs. Fall. 2 Lect., 1 (2½-hour) Rec.-Comp. Prerequisites, Math. 192 and Physics 122 and co-registration in Math. 293 and Physics 223. The main topics are the same as those in 241, but their treatment is more analytical and more intensive.

244. ELECTRICAL SCIENCE II.

Credit 3 hrs. Spring. 2 Lect., 1 (2½-hour) Rec.-Comp. Prerequisites, Elec. Sci. 243, Math. 293 and Physics 223 and co-registration in Math. 294 and Physics 224. The main topics are the same as those of 242, but their treatment is more analytical and more intensive.

Mechanics

211. MECHANICS OF RIGID AND DEFORMABLE BODIES I

Credit 4 hrs. Fall-Spring. 1 Lect., 2 Rec., 1 (2½-hour) Comp.-Lab. Prerequisites, co-registration in Math. 293 and Physics 223. Force systems and equilibrium. Distributed forces, static friction, statically determinate plane structures. Concepts of stress and strain. Shearing force, bending moment, bending and tension of beams. Analysis of plane stress and strain, combined stress, thermal stress. Theories of failure. Instability of columns. Staff. (Evening prelims.).

212. MECHANICS OF RIGID AND DEFORMABLE BODIES II

Credit 4 hrs. Spring-Summer. 1 Lect., 2 Rec., 1 (2½-hour) Comp.-Lab. Prerequisite, Mechanics 211. Inelastic behavior. Energy methods in mechanics. Principles of particle dynamics. Theory of oscillations. Kinematics of rigid body motion. Dynamics of systems of particles. Kinetics of rigid bodies. Staff (Evening prelims.)

Materials Science

6211. MATERIALS SCIENCE

Credit 3 hrs. Spring. Lectures and Laboratory. Prerequisite, Physical Chemistry 276. A fundamental course considering stable and mestastable aggregations of atoms into real materials, the properties of materials, and the relationship of structure to properties. The effect of mechanical and physical forces on the properties of materials are treated. The laboratory includes experiments on crystallography, phase equilibria, microscopy, crystal imperfections, diffusion, and mechanical properties.

Chemical Engineering

5101. MASS AND ENERGY BALANCES

Credit 3 hrs. Fall. 3 Lect., 1 Comp. period. Parallel, Physical Chemistry 285. Engineering problems involving material and energy balances. Flow-sheet systems and balances. Total energy balances for flow systems. Mr. Thorpe.

5102. EQUILIBRIA AND STAGED OPERATIONS

Credit 3 hrs. Spring. 3 Lect., 1 Comp. period. Parallel, Physical Chemistry 286. Phase equilibria and phase diagrams. The equilibrium stage, mathematical descripion of single and multistage operations, analytical and graphical solutions. Mr. Thorpe.

COMPUTER SCIENCE

201. SURVEY OF COMPUTER SCIENCE

Credit 3 hrs. 3 Lect.-Rec. Introduction to and survey of the field of computer science. Designed to provide an understanding of the present and potential influence of the computer sciences on our society. Will consider the nature and characteristics of automatic computing equipment and programming languages in sufficient detail for students to gain an appreciation of the advantages and limitations of modern computers. Will consider applications in a wide range of areas such as the humanities, the physical and social sciences, industry, and government. Students will program problems for the computer in Rand Hall. This course alone does not satisfy the prerequisites for any other course in computer science.

301. INTRODUCTION TO COMPUTER SCIENCE (Same as Engineering 9381)

Credit 3 hrs. 2 Lect., 1 Rec.-Comp. Prerequisites, Math. 293 or equivalent. Introduction to the field of computer science including principles and characterestics of information processing equipment, programming languages, and applications. Topics are selected to illustrate a wide range of current and potential areas of application with emphasis being placed on the modern digital computer as a symbol-manipulating device rather than as an arithmetic calculator. Number systems, computer logic and organization, and characteristics of current equipment are covered along with various aspects of programming. Also, introductory concepts and problems associated with using computers in information processing systems, real-time control systems, simulated experimentation, and the design process are also considered. Laboratory work involves use of the facilities at the Cornell Computing Center, but this is not primarily a course in programming.

321. NUMERICAL CALCULUS (Same as Math. 325)

Credit 4 hrs. 3 Lect. Prerequisite, Math. 213, or equivalent. The computational aspects of calculus and related mathematics in the light of modern computing machines. Numerical differentiation and integration, solution of algebraic and differential equations, interpolation, and simple error analysis of these processes. The student is expected to know CORC, the Cornell computing language.

370. AUTOMATA (Same as Math. 390)

Credit 3 hrs. Spring. Prerequisites, Math. 294 or Math. 222, or equivalent. Both the engineering and mathematical aspects of automata will be introduced. Examples of mathematical topics: finite-state machines, neural nets, input-output machines, Turing machines, computability. Examples of engineering topics: machines that learn, adaptive systems, pattern recognition, self-reproducing and self-repairing machines, system reliability, threshold logic systems, biological models, heuristic programming, industrial and technological applications, progress in devices, automatic language translation, cybernetics and robots.

401. INTRODUCTION TO COMPUTER SCIENCE (Same as Engineering 9481)

Credit 4 hrs. 3 Lect. 1 Rec.-Comp. This course covers the same topics as Computer Science 301. Two lectures are held concurrently with 301, and an independent third lecture and independent recitation-computing are scheduled for 401. This permits 401 to treat the same subject matter as 301 but in greater depth for graduate students.

411. PROGRAMMING SYSTEMS AND THEORY I

Credit 3 hrs. 3 Lect.-Rec. Prerequisite, Computer Science 301 or equivalent. Concerned with assembly-level and machine-level programming of large-scale digital computing systems. Will consider principles and techniques involving indirect addressing, index registers, input-output control, program interrupts, storage allocation, magnetic tape and disc auxiliary storage, diagnostic methods and routines. Also, advanced programming systems for executive control. Students will program problems for the Control Data 1604–160A at the Cornell Computing Center.

412. PROGRAMMING SYSTEMS AND THEORY II

Credit 3 hrs. 3 Lect.-Rec. Prerequisite, Computer Science 411 or equivalent. Concerned with theory and techniques of programming languages and programming systems for large scale digital computer systems. Will consider programmng aspects of time-sharing, multiprogramming, real-time, and satellite systems. Also, the structure and form of different types of programming languages including assemblers, interpreters, compilers, and list processors. Basic techniques for scanning, ordering, and translating will be covered. Students will design and implement several simple programming languages during the term.

413. DIGITAL COMPUTER PROGRAMMING

Credit 1, 2, or 3 hrs. 2 Rec., 1 Comp. Intended for graduate students; undergraduates should ordinarily take 201 or 301. Prerequisite, consent of instructor. Intended to prepare students to use the digital computers of the Cornell Computing Center in a language other than CORC. The course consists of three independent five week sections with one hour of credit for each section. Each section will consider one language from the following: FORTRAN, ALGOL, COBOL, CODAP. The particular languages to be covered and the order of presentation will be posted at the Computing Center at the beginning of the term. Program test procedures and input-output operations including the use of magnetic tape systems will also be covered.

421. NUMERICAL ANALYSIS

Credit 4 hrs. Prerequisite, Math. 222 or the equivalent, and Computer Science 301, or consent of the instructor. 3 Lect. This course covers essentially the same topics as Computer Science 321 but in a more complete fashion and with more emphasis on error analysis and mathematical rigor.

422. NUMERICAL ANALYSIS (Same as Math. 426)

Credit 4 hrs. Prerequisite, Computer Science 421, or consent of the instructor. 3 Lect. Numerical methods in matrix analysis and the solution of partial differential equations.

431. DATA PROCESSING SYSTEMS (Same as BPA-901)

Credit 3 hrs. 3 Lect.-Rec. An introductory course in modern data processing systems for graduate students not in Computer Science. Considers problems and techniques associated with using modern data-handling systems in various organizational environments such as industry, government, and hospitals. Includes an introduction to data-handling equipment, programming, and applications. Considers control and decision functions as well as routine operations. Emphasis is more on problem analysis and systems planning than on programming although students will have programs run at the Cornell Computing Center.

433. ADVANCED DATA PROCESSING SYSTEMS (Same as Engineering 9582)

Credit 3 hrs. 2 Rec., 1 Comp. Prerequisite, Computer Science 301 or 431, or permission. Concerned with design of integrated data processing systems for operational and financial control: questions of system organization, languages and equipment appropriate to this type of application, file structures, addressing and search problems, sorting techniques; problems of multiple-remote-input, on-line data processing systems; techniques of system requirement analysis.

435. INFORMATION ORGANIZATION AND RETRIEVAL

Credit 3 hrs. 3 Lect.-Rec. Prerequisite, Computer Science 301. A study of the theory, problems, and techniques associated with the efficient storage and retrieval of numeric and non-numeric information. Will consider topics in document identification and retrieval as well as content retrieval. Current research in this area will be explored following the development of basic concepts and theory.

437. DIGITAL SYSTEMS SIMULATION (Same as Engineering 9580)

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Prerequisites, Computer Science 301 and a course in probability. The use of a program for a digital computer to simulate the operating characteristics of a complex system in time. Discussion of problems encountered in construction of a simulation program; synchronization and file maintenance, random number generation, random deviate sampling. Programming in the CLP and SIMSCRIPT languages. Problems in the design of effective investigations using simulation; statistical considerations when sampling from a simulated process. Applications of simulation to queuing, storage, traffic, and feedback systems. Applications will include use in the design of facilities, design of operating disciplines, and use in real-time control of an operating system.

441. COMPUTATIONAL LINGUISTICS

Credit 3 hrs. Prerequisite, Linguistics 201 or 301, Linguistics 413, or Computer Science 301, or equivalents. Consideration of mathematical characterization of natural languages and discussion, in this context, of the characteristics of programming languages; approaches to generating and parsing natural language data; computer applications to the processing of natural languages data.

461. SWITCHING SYSTEMS I (Given as E.E. 4587)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisites, E.E. 4322, or consent of instructor. Switching algebra; switching devices; logical formulation and realization of combinational switching circuits; minimization aids; number representation and codes; simple memory devices; synchronous sequential circuits; counters; shift registers, and arithmetic units in a digital computer.

462. SWITCHING SYSTEMS II (Given as E.E. 4588)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, Computer Science 461, or equivalent. Synchronous and asynchronous sequential circuits, formulation and optimization; large-scale memory units, selection and control; further discussion of arithmetic units; integrated study of switching systems including general-purpose digital computer, control switching, and communication switching; introduction to the general theory of learning machines.

467. ANALOG COMPUTATION (Given as E.E. 4583)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisites, E.E. 4302 and concurrent registration in EE 4401, or consent of the instructor. Concepts and principles of analog computation; scaling and programming of linear, non-linear, and time-varying differential equations; direct simulation of electrical and mechanical systems; analog programming using digital logic. Laboratory work involves solution of problems on a general-purpose analog computer. It can also be devoted in part to special student projects.

490. SPECIAL INVESTIGATIONS IN COMPUTER SCIENCE

Credit and sessions as arranged. Either term. Offered to qualified students individually or in small groups. Directed study of special problems in the field of Computer Science. (Register only with the registration officer of the department.)

491. COMPUTER SCIENCE GRADUATE SEMINAR

Credit 1 hr. Both terms. For graduate students. A weekly one and one-half hour meeting for discussion and study of important topics in the field.

THEORETICAL AND APPLIED MECHANICS

211. MECHANICS OF RIGID AND DEFORMABLE BODIES I

Credit 4 hrs. Fall-spring. 1 Lect., 2 Rec., 1 Comp.-Lab. Co-registration in Math. 293 and Physics 223. Force systems and equilibrium. Distributed forces, static friction, statically determinate plane structures. Concepts of stress and strain. Shearing force, bending moment, bending and torsion of beams. Analysis of plane stress and strain, combined stress, thermal stress. Theories of failure. Instability of columns. Staff. (Evening prelims.)

212. MECHANICS OF RIGID AND DEFORMABLE BODIES II

Credit 4 hrs. Spring. 1 Lect., 2 Rec., 1 Comp.-Lab. Prerequisite, 211. Inelastic behavior. Energy methods in mechanics. Principles of particle dynamics. Theory of oscillations. Kinematics of rigid body motion. Dynamics of systems of particles. Kinetics of rigid bodies. Staff. (Evening prelims.)

900. AUTOMATA (MATH. 390)

Credit 3 hrs. Spring. 3 Rec. Prerequisite, Math. 293–294 or Math. 221–222, or equivalent. Both the engineering and mathematical aspects of automata will be introduced. Examples of mathematical topics: Finite-state machines, neural nets, input-output machines, Turing machines, computability. Examples of engineering topics: Machines that learn, adaptive systems, pattern recognition, self-reproducing and self-repairing machines, system reliability, threshold logic systems, biological models, heuristic programming, industrial and technological applications, progress in devices, automatic language translation, cybernetics and robots. Mr. Block.

1159. EXPERIMENTAL MECHANICS

Credit 3 hrs. Spring. 1 Rec., 2 Lab. Primarily for graduate students and qualified undergraduates. Brittle coating method of experimental stress analysis. Electrical resistance type strain gages, including factors influencing alloy sensitivity, gage construction, gage factors, stress gages. Instrumentation for static and dynamic strain gage work including a brief coverage of amplifiers, galvanometers, recorders, and oscilloscopes. Photoelastic methods of stress analysis, photostress. Mr. Moynihan.

1160. APPLIED MECHANICS OF SOLIDS

Credit 3 hrs. Fall. 3 Lect. Graduates and qualified undergraduates. A unified approach to elastic, plastic and time dependent material behavior, with special emphasis on the relationship between the physical aspects of the subject and mathematical theory. Kinematics of the continuum, balance of momentum, stress hypothesis, compatibility, boundary conditions, uniqueness, extremum principles including energy methods, constitutive equations. Special topics selected from finite elasticity theory, Stokesian fluids, plasticity, linear visco-elasticity, hypoelasticity. Mr. Lance.

1162. THEORY OF VIBRATION

Credit 4 hrs. Fall. 3 Lect., 1 Lab. Prerequisite, 1180 or equiv. or consent of instructor. Graduates and qualified undergraduates. Vibration of lumped systems including free and forced vibration, damping, impedance methods, resonance, vibration isolation. Matrix methods. Continuous systems including strings, membranes, torsion and bending of beams, plates. Rayleigh-Ritz Method. Impact and transient response. Applications include vibrations of structures and machine elements. Mr. Pao.

1163. APPLIED ELASTICITY

Credit 3 hrs. Fall. 3 Lect. Graduates and qualified undergraduates. Analysis of thin curved bars. Plane stress and plane strain in the circular cylinder, effects of pressure, rotation, and thermal stress. Small and large deflection theory of plates, classical and approximate methods. Strain energy methods. Symmetrically loaded thin cylindrical shell. Torsion of thin-walled members. A first course in the mechanics of elastic deformable bodies with structural applications. Mr. Conway.

1164. THEORY OF ELASTICITY I

Credit 3 hrs. Spring. 3 Lect. General analysis of stress and strain. Plane stress and strain. Airey's stress function solutions using Fourier series, Fourier integral, and approximate methods. St. Venant and Michell torsion theory. Simple three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space. Mr. Conway.

1165. THEORY OF ELASTICITY II

Credit 3 hrs. Spring. 3 Lect. Graduate students. Development in tensor form of the basic equations of large deformation elasticity; solution of certain large deformation problems. Linearization to infinitesimal elasticity. Boussinesq-Papkovich potentials and their application to three-dimensional problems; contact problems; plane stress by method of Muskhelishvili; application of conformal mapping; Cauchy integral techniques in elasticity; torsion problems. Mr. Lance.

1166. STRESS WAVES IN SOLIDS

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 1162, 1163, or equivalent. Graduate students. General equations of elastodynamics. Waves in extended elastic media. Reflection and refraction of waves. Surface waves and waves in layered media. Vibrations and waves in strings, rods, beams and plates. Dispersion in mechanical wave-guides. Transient loads. Scattering of elastic waves and dynamical stress concentration. Waves in anisotropic media and visco-elastic media. Mr. Pao.

1167. THEORY OF PLATE AND SHELL STRUCTURES

Credit 3 hrs. Spring. 3 Lect. Graduate students and qualified undergraduates. Analysis of deformation and stress in plates and flat slabs under transverse loads. Various boundary conditions. Numerical methods. Membrane stresses and displacements in shells under various loading. Bending theory of shells. Applications to shell-type structures such as submarines, aerospace structures shell roofs, pressure vessels. Mr. Bijlaard.

[1168. THEORY OF PLASTICITY

Credit 3 hrs. Fall. 3 Lect. Graduate students and qualified undergraduates. Theory of inelastic behavior of materials. Plastic stress-strain laws, yield criteria and flow laws. Flexure and torsion of bars, thick-walled cylinders, metal forming and cutting, stress analysis in metals and soils. Yield hinges. Limit analysis. Shakedown of simple statically indeterminate members. Not offered in 1965–66.]

1169 THEORY OF ELASTIC AND INELASTIC STABILITY

Credit 3 hrs. Fall. 3 Lect. Graduate students and qualified undergraduates. Various cases of instability. Derivation of elastic and inelastic buckling loads of columns with various boundary and continuity conditions, truss members, frames, etc., by various methods, such as direct solution from differential equations as eigenvalue problems, by Haarman method, energy methods, matrix method using digital computer. Buckling of composite structures such as columns with batten plates, latticed columns by Haarman method and method of split rigidities. Buckling of plates with various boundary conditions. Solutions for buckling of plate assemblies by solving of differential equations and by method of split rigidities. Theory of inelastic buckling of plates and shells. Buckling and forced crippling of stringerpanels in airplane wings. Interaction of column and plate buckling. Buckling of sandwich plates with various boundary conditions. Derivation of post-buckling load of plates. Buckling load of columns in post-buckling range of the composite plates. Buckling of cylindrical, spherical and conical shells under external pressure. Cylindrical shells evenly stiffened by rings. Cylindrical shells under axial compression and bending. Buckling of sandwich shells. Mr. Bijlaard.

1170. ADVANCED DYNAMICS

Credit 3 hrs. Spring. 3 Lect. Graduate students and qualified undergraduates. Newton's equations of motion for a system of masses, their solution, momentum, energy. Systems with variable mass, rocket equations. Variational principles of mechanics, d'Alembert's principle, Legrange's equations, Hamilton's equations. Stability of motion, Liapunov's method. Rigid body motion, Euler's equations, tops, gyroscopes. Theory of small oscillations. Mr. Cranch.

1171. ARTIFICIAL SATELLITE THEORY

Credit 3 hrs. Fall. 3 Lect. Graduate students and qualified undergraduates. Potential of earth; two-body problem; Hamilton Jacobi theory; orbit about spherical and nonspherical earth; Von Zeipel's method; vector theory of perturbations; Hansen's method; atmospheric drag and solar radiation effects on orbit; charged satellite in earth's magnetic field; lunar and solar perturbations; orbits of lunar satellites; attitude control of satellites. Mr. Mitchell.

1172. SPACE FLIGHT MECHANICS

Credit 3 hrs. Spring. 3 Lect. Graduate students and qualified undergraduates. Three-body problem; regularization; Jacobi integral; restricted three-body problem; Hill curves; libration points and stability; motion in cislunar space; interplanetary trajectories; space navigation; limiting problems in space travel; theory of optimal trajectories; Pontryagin maximum principle; rendezvous problems. Mr. Mitchell.

1175. OSCILLATIONS IN NONLINEAR SYSTEMS

Credit 3 hrs. Spring. 3 Lect. A study of the methods of analysis of nonlinear electrical and mechanical systems. Theory of differential equations, phase plane analysis, stability criteria, comparison between linear and nonlinear methods. Equations of van der Pol, Duffing, Mathieu, Floquet, Hill. Poincaré-Bendixson theorem, orbital stability. Methods of van der Pol, Poincaré, Kryloff and Bogoliuboff, Galerkin, Ritz, harmonic balance, equivalent linearization, graphics, perturbations. Hysteresis. Application of Banach Space techniques.

1180. METHODS OF APPLIED MATHEMATICS I

Credit 3 hrs. Fall. 3 Lect. Prerequisite, one-semester course in ordinary and partial differential equations. Ordinary differential equations; series; orthogonal functions and Sturm-Liouville theory; Green's function; Fourier and Laplace transforms; functions of several real variables; vector analysis; matrices; partial differential equations; with application to engineering problems. Mr. Greenberg.

1181. METHODS OF APPLIED MATHEMATICS II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 1180. Continuation, from 1180, of partial differential equations; complex variable; tensor analysis; calculus of variations; with application to engineering problems. Mr. Greenberg.

1182. METHODS OF APPLIED MATHEMATICS III

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 1181 or equivalent. Application of advanced mathematical techniques to engineering problems. Conformal mapping; complex integral calculus; Green's function; integral transforms; asymptotics including steepest descent and stationary phase; Wiener-Hopf technique; general theory of characteristics; perturbation methods; singular perturbations including PLK method and boundary layers. Development will be in terms of problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, electro-magnetics. Mr. Ludford.

1183. METHODS OF APPLIED MATHEMATICS IV

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 1182 or equivalent. More extensive treatment of 1182 in same spirit. Topics include: method of matched asymptotic expansions, W.K.B. approximation; Hilbert-Schmidt and Fredholm theories of integral equations; singular integral equations, Wiener-Hopf equations with application to finite interval, Carleman equation and its generalization, effective approximations; further methods in partial differential equations, slot problems. Mr. Ludford.

1184. NUMERICAL METHODS IN ENGINEERING

Credit 3 hrs. Spring. Prerequisite, 1181 or equivalent. Methods for obtaining numerical solutions to problems arising in science and engineering, such as boundary value problems, eigenvalue problems, diffusion, conduction, wave propagation, vibrations. Variational and integral equation techniques are developed. Mr. Moran.

1196. RESEARCH IN THEORETICAL AND APPLIED MECHANICS

Credit as arranged. Thesis or independent research in a field of theoretical and applied mechanics. Such research must be under the guidance of a staff member. Staff.

1197. SELECTED TOPICS IN THEORETICAL AND APPLIED MECHANICS

Credit as aranged, any term. Qualified students wishing to do work in any field of theoretical and applied mechanics should register for this course after consultation with the department. Students work with appropriate members of the staff in the chosen field. Typical areas of work include theory of elastic stability, theory of plates and shells, rocket theory and design, wave propagation, elasticity, vibrations, and experimental mechanics. Staff.

CIVIL ENGINEERING

Civil Engineering Materials

Mr. Slate

2001. ENGINEERING MATERIALS

Credit 3 hrs. Fall & Spring. 2 Lect., 1 Lab. Prerequisite, 6311. Engineering properties of concrete; engineering properties of steel, wood, and other selected structural materials; physico-chemical properties of soils, concrete, and bituminous materials. Design characteristics and significance of test results of materials used in engineering works. Extensive laboratory testing and report writing.

2010. ADVANCED PLAIN CONCRETE

Credit 2 hrs. Spring. 2 Lect. Prerequisite, 2001 or the equivalent. Topics in the field of concrete, such as history of cementing materials, air-entrainment, light weight aggregates, petrography, durability, chemical reactions, and properties of aggregates. Relationships between internal structure, physical properties, chemical properties, and the mechanical properties of interest to the design and construction engineer.

2011. STRUCTURE AND PROPERTIES OF MATTER

Credit 3 hrs. Fall. 2 Lect. plus conference. Open to graduate students in engineering or the physical sciences or by consent of instructor. Internal structure of materials ranging from the amorphous to the crystalline state. Correlation of the internal structures of materials with their physical and mechanical properties, primarily on a qualitative basis. Applications to various engineering materials.

2041. CIVIL ENGINEERING MATERIALS PROJECT

On demand. Credit 1–6 hrs. Individual projects involving civil engineering materials.

2042. CIVIL ENGINEERING MATERIALS RESEARCH

On demand. Hours and credit variable. Individual assignments, investigations and/or experiments with civil engineering materials.

2044. SPECIAL TOPICS IN MATERIALS

On demand. Hours and credit variable. Fall-spring.

Surveying

Messrs. Lyon, McNair.

2101. ENGINEERING MEASUREMENTS

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Study of basic surveying instruments and of procedures for measuring and laying out angles, distances, areas, and volumes; data processing and presentation of results of measurement operations; geometric geodesy; photogrammetry; field astronomy; graphical and numerical representation of topography; and planning and specifications for surveying operations.

2107. ELEMENTS OF SURVEYING

Credit 2 hrs. Fall-spring. 1 Rec., 1 Lab. Fundamentals of engineering measurements. Study of observations and errors. Principles of recording data. Use of steel tape, level, and transit. Optical tooling. Photogrammetry. Problems of particular interest to students in fields other than civil engineering.

2111. ELEMENTARY GEODESY

Credit 3 hrs. Fall. 3 Rec. Principal problems of geodesy. Coordinate systems, reference datum. Geometric problems on earth ellipsoid. Geometric astronomy. Bjerhammar singular matrix calculus; singular matrices in geometry.

2112. GEOPHYSICAL GEODESY

Credit 3 hrs. Spring. 3 Rec. Basic potential theory, Laplace and Poisson equations; gravity and potential field in, on, and outside the spheroid; figure of the earth, application of Stokes formula for determining undulations of the geoid and deflection of the vertical; applications of spherical harmonics.

2113. GEODETIC CONTROL SURVEYS

Credit 3 hrs. 2 Rec., 1 Lab. Prerequisite, 2102 or 2111. Principles of establishing a geodetic sea-level datum; isostasy, the geoid and ellipsoid; altimetry, trigonometric, spirit, and electronic leveling; orthometric and dynamic heights; electronic distance measurement; triangulation and trilateration; design of control networks and systems; astronomic and gravimetric observations, and satellite triangulation.

2115. ADVANCED ENGINEERING MEASUREMENTS

Credit 3 hrs. Fall. Prerequisites, laboratory work involving physical measurements, Math 294, and permission of the instructor. Measurement systems; analysis of errors and of error propagation; application of the principles of probability to the results of measurements for the purpose of determining the best estimates of measured and deduced quantities, and the best estimate of uncertainty in these quantities; adjustment of conditioned measurements by the method of least squares and other methods; curve fitting; and related data processing methods.

2119. MAP PROJECTIONS

On demand. Credit 3 hrs. Theory of map projections including conformal, equal-area, azimuthal equidistant, et al. projections; coordinate transformations; plane coordinate systems for surveying.

2121. ELEMENTS OF PHOTOGRAMMETRY

Credit 3 hrs. Fall. Lect., Rec., Lab. Principles and practice of terrestrial and aerial photogrammetric mapping, including planning flights, control surveys, uncontrolled mosaics, radialline control, simple stereoplotting instruments, parallax distortions, graphical tilt determination, trimetrogen charting, and economics. A Balplex projection stereoplotter with three projectors is available for use.

2122. ADVANCED PHOTOGRAMMETRY

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Prerequisite, 2121. An advanced study of photogrammetric principles including: controlled mosaics; rectification; graphical and instrumental aerotriangulation. Principles of photogrammetric plotters and systems and the economic relation of these to density of ground control, office methods, and personnel. Balplex projection plotter is used extensively.

2123. ANALYTIC AEROTRIANGULATION

Credit 3 hrs. 3 Rec. Prerequisite, 2121. Analysis, theories, and computation of stereostrip triangulation by direction cosines, vector, and matrix methods. Coplanarity and colinearity equations for relative orientation and absolute orientation. Stereogram assemblage and coordinate transformation of strip and block coordinates. Cantilever extension and general bridging solutions. Propagation of errors.

2131. LAND SURVEYING

On demand. Credit 3 hrs. 3 Rec. Prerequisite, permission of the instructor. Functions and responsibilities of a land surveyor; deeds and land descriptions; land records and land courts. Study of U.S. public land system, metes and bounds, subdivisions, resurveys, cadastral surveys, riparian rights, mineral land surveys, and other land survey systems. Specifications and registration.

2132. CARTOGRAPHY

On demand. Credit 2 hrs. Study of the needs of map users and methods of production of maps to meet these needs. Cartographic principles, systems, and economics.

2133. ENGINEERING SURVEYS

Credit 3 hrs. Spring. 1 Rec., 2 Labs. Prerequisite, 2101 or equivalent. Circular curves, transition curves, earthwork measurement and calculation, construction surveys and project planning from maps.

[2134. SUMMER SURVEY CAMP

Not offered in 1965–66.]

2141. PROJECT. GEODETIC OR PHOTOGRAMMETRIC ENGINEERING

On demand. Open to specially selected seniors or graduate students. Projects in the various fields of geodesy and photogrammetry may be developed by conference between professors and students. Hours and credit variable.

2142. GEODETIC OR PHOTOGRAMMETRIC ENGINEERING RESEARCH

On demand. Prerequisites will depend upon the area of studies to be pursued. Special problems in error analysis, geodesy, and photogrammetry as may be arranged.

2143. SEMINAR IN GEODESY OR PHOTOGRAMMETRY

On demand. Credit 1–6 hrs. Open to specially selected seniors or graduate students. Abstraction and discussion of technical papers and publications in the geodetic or photogrammetric field.

Hydraulics and Hydraulic Engineering

Messrs. Brutsaert, Graf, Liggett, and staff.

2301. FLUID MECHANICS

Credit 3 hrs. Fall. 3 Lect.-Rec. Fluid properties, hydrostatics, the basic equations of fluid flow, potential flow, dimensional analysis, flow in conduits, open channel flow. Staff.

2302. HYDRAULIC ENGINEERING

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Prerequisite, 2301. Free surface flow, fluid meters and measuring devices, hydraulic machinery, unsteady flow, network analysis. The laboratory will include a number of experiments in fluid mechanics and hydraulic engineering. Mr. Graf.

2303. HYDROLOGY (Formerly 2302)

Credit 2 hrs. Fall. 2 Lect.-Rec. Prerequisite, 2301. Introduction to hydrology including topics on precipitation, evapotranspiration, ground water, surface water, and sedimentation. Staff.

2311. ADVANCED HYDRAULICS

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 2301. Intended as an extension of the elementary fluid mechanics. Primarily for students not majoring in civil engineering or those who have not received their undergraduate training at Cornell. Basic equations, potential flow, flow in conduits, boundary layer theory, open channel flow, water hammer and surges, hydraulic models, and compressible flow. Special problems. Staff.

2312. EXPERIMENTAL AND NUMERICAL METHODS IN FLUID MECHANICS

Credit 2 hrs. Fall-spring. Prerequisite, 2302 or permission of instructor. Primarily a laboratory course for undergraduates and graduates; may be repeated for credit on permission of the instructor. Emphasis is on planning and conducting laboratory and field experiments and on numerical computation. Each section is limited to 4 students. Staff.

2315. ADVANCED FLUID MECHANICS I

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 2301. Introduction to vector and tensor notation. The equations of conservation of mass, momentum, and energy from a rigorous point of view. Similitude and modeling potential flow including circulation, vorticity, conformal mapping, and hodograph methods. Mr. Liggett.

2316. ADVANCED FLUID MECHANICS II

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 2315. Exact solutions to the Navier-Stokes equations, the laminar and turbulent boundary layers, turbulence, introduction to non-Newtonian flow, and other topics. Mr. Liggett.

2317. FREE SURFACE FLOW

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 2315 or permission of instructor. The formulation of the free surface equations and boundary conditions. Shallow water theory and the theory of characteristics. Unsteady and two-dimensional flow in open channels. Theory of small amplitude waves. Mr. Liggett.

2320. SURFACE-WATER HYDROLOGY

Credit 3 hrs. Fall. Prerequisite, 2301. Physical analysis and design relative to hydrologic processes. Hydrometerology, runoff, floods, unit-hydrograph procedures, channel and reservoir routing. Staff.

2321. FLOW IN POROUS MEDIA

Credit 3 hrs. Spring. Prerequisite, 2301 (also recommended, 2315). Fluid mechanics of flow through porous solids. The general equations of single phase and multiphase flow and the methods of solving the differential form of these equations. Hydraulics of wells, of infiltration and of ground water recharge, and of other steady state and transient seepage problems. Staff.

2331. RIVER AND COASTAL HYDRAULICS

Credit 3 hrs. Fall. Prerequisite, 2302 or permission of instructor. The first part of this course deals with the hydraulics of fixed bed channels including the specific energy concept, secondary currents, rapid flow problems, artificial obstructions in channels, and the general problem of frictional resistance. In the second part of the course attention is paid to coastal and oceanographical engineering problems including the theory of waves, breaking of waves, wave refraction and wave diffraction. Mr. Graf.

2332. SEDIMENT TRANSPORT

Credit 3 hrs. Spring. Prerequisite, 2331 or permission of instructor. Hydraulics of channels with a movable bed including particle mechanics, critical tractive force theory, the DuBoys Problem, the Swiss formulas, Einstein's Bedload theory, the suspension and saltation theory, calculation of total sediment loads. Interesting problems in fluvial hydraulics will be included. Mr. Graf.

2341. PROJECT

Offered on demand. Hours and credit variable. The student may elect a design problem or undertake the design and construction of a special piece of equipment in the fields of fluid mechanics, hydraulic engineering or hydrology.

2342. RESEARCH IN HYDRAULICS

Offered on demand. Hours and credit variable. The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either of an experimental or theoretical nature. Results should be submitted to the instructor in charge in the form of a research report.

2343. HYDRAULICS SEMINAR

Credit 1 hr. Fall-spring. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering. Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology are presented and discussed.

2344. SPECIAL TOPICS IN HYDRAULICS

Offered on demand. Hours and credit variable. Special topics in fluid mechanics, hydraulic engineering, or hydrology are presented when a group of students expresses an interest or when an especially qualified person appears on campus.

Soil Engineering

Mr. Esrig

2401. ELEMENTS OF SOIL ENGINEERING

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Properties of soil and its behavior as an engineering material. Principles of soil identification and classification, terminology and soil characteristics such as graduation, permeability, compressibility, consolidation, and shearing strength with application to simple problems of seepage, settlement, bearing capacity, stability of earth slopes. Lateral earth pressure. Soil exploration. Laboratory tests for experimental determination of above-mentioned soil characteristics, and evaluation and use of data.

2406. FOUNDATIONS

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 2702 and 2401. Study of soil and structural problems encountered in foundation engineering. Dewatering, slope stability, retaining walls, bulkheads, spread footing, pile and pier foundations. Design problems.

2410. ENGINEERING PROPERTIES OF SOILS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 2401. Soil structure, adsorbed and free water. Flow of water through soil, flow nets, piezometers, filters, piping, capillary flow, soil suction, and frost action. Uniaxial and triaxial consolidation, volume compressibility and pore pressure coefficients, shrinkage and swelling. Shear strength of saturated and partly saturated, isotropically and anisotropically consolidated soils, true and apparent cohesion and friction resistance, sensitivity and thixotrophy, triaxial, direct shear, penetration and vane tests.

2412. PRINCIPLES OF SOIL ENGINEERING

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 2401. Failure theories for soils, general and local shear failures. Kotter's equation and boundary conditions. Lateral earth pressures, Rankine, Coulomb, logarithmic spiral and friction circle methods. Bearing capacity of deep and shallow foundations, eccentric and inclined loading, size and shape effects. Stability of slopes, methods of slices, seepage pressures. Soil pressures, concentrated and distributed loads, influence charts, soil modulus, contact pressures, and pressure cells. Mr. Esrig.

2414. APPLIED SOIL ENGINEERING I

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 2401 and 2412. Long- and short-time strength of soils, numerical methods. Footings and rafts, design criteria, elastic foundations, construction problems, plate load tests. Piles and caissons, pile tests, pile driving formulas, dynamic and static penetration tests, ultimate strength and settlements of pile groups, stress wave equation, buckling and lateral resistance. Retaining walls, shallow and deep-seated failures, seepage pressures.

2416. APPLIED SOIL ENGINEERING II

Credit 2 hrs. Spring. 2 Lect. Prerequisite, 2412 or consent of instructor. Soil exploration and sampling including geophysical methods as applied to foundation, construction, and ground water problems. Design of boring programs and interpretation of field data. Bulkheads and bracing, design criteria, behavior at ultimate and working loads, design of earth and rock fill dams, upstream and downstream slopes, flow nets, concept of safety and load factors. Design and stability evaluation of cofferdams, effects of construction procedures on lateral earth pressures. Tunnels, geological considerations, factors affecting tunnel lining design, special problems.

2418. EVALUATION OF SOIL PROPERTIES

Credit 3 hrs. Spring. 1 Lect. 2 Labs. Prerequisite, 2410 or consent of instructor. Laboratory evaluation of the parameters used in modern soil mechanics and soil engineering. Emphasis is placed on the relationship of these measured parameters to those needed in design. Consideration is given to the effects of sampling methods on the soil parameters. Experiments include permeability, direct shear, triaxial and consolidation testing.

2441. PROJECT

On demand. Hours and credit variable. Projects may be selected from the various fields of soil engineering such as shear strength and consolidation characteristics of soils, stabilization, soil-structure interaction, behavior of soils under dynamic loads, etc. Also, design problems such as pile foundations, sheet pile walls, earth or rock fill dam tunnels, cofferdams may be chosen which are of particular interest to the student.

2442. SOIL ENGINEERING RESEARCH

On demand. Credit 1–6 hrs. Students who wish to study one particular area in soil engineering to some depth. The work could be in the form of a laboratory investigation, theoretical analysis of the behavior and failure modes of earth structures or the development of design methods.

2443. SOIL ENGINEERING SEMINAR

On demand. Credit 1–2 hrs. Presentation and discussion of technical papers and current research in the field of soil engineering. Open to seniors and graduate students.

2444. SPECIAL TOPICS IN SOIL ENGINEERING

On demand. Credit 1–6 hrs. Supervised studies in small groups (2–3 students) in one or more of the special topics in the field of soil engineering which are not covered in the regular courses. Hours and credit variable.

Sanitary Engineering

Messrs. Behn, Dworsky, Gates, Loucks, Lynn, Wollhiser, and staff.

2501. WATER SUPPLY AND WASTE-WATER ENGINEERING

Credit 3 hrs. 2 Lect. 1 Lect.-Dem. Fall. Prerequisite, 2301. Concurrent registration in 2302. Introduction to water resources engineering, including water quality and water quality control. Principles applicable to the disposal, assimilation, and fate of municipal and industrial wastes in the environment. Analysis and design of water transmission and distribution systems, and of waste-water and storm-water collection and disposal systems.

2502. WATER AND WASTE-WATER TREATMENT PROCESSES

Credit 3 hrs. 2 Lect., 1 Lab. Spring. Prerequisites, 2301, 2302. Study of the microbiological, chemical, and physical phenomena underlying the treatment of water and of municipal and industrial waste-water. Application of these principles to the analysis and design of unit treatment processes. Laboratory studies of water quality and of unit treatment processes.

2509. ENVIRONMENTAL SANITATION

Open to non-civil engineering students. Credit 3 hrs. Fall. Lect.-Discuss., reports and field trips. Environmental health concepts and methods, and their application to environmental planning and control at the subdivision, municipal, and metropolitan levels. Introduction to: water resource planning and development; water quality control; water supply; municipal, industrial and private waste-water disposal; air quality control; solid waste disposal and radiological health.

2510. CHEMISTRY OF WATER AND WASTE-WATER

Credit 3 hrs. 2 Lect.-Rec., 1 Lab. Fall. Prerequisite, one year of college chemistry. Principles of chemistry applicable to the understanding, design and control of water and waste-water treatment processes and to reactions in receiving waters. Analytical methods applicable to the measurement and control of air and water quality.

2512. MICROBIOLOGY OF WATER AND WASTE-WATER

Credit 3 hrs. 2 Lect., 1 Lab. Spring. Introduction to the characteristics of microorganisms and their interaction with the environment; their effect on water quality. Their role in the biological oxidation of organic substances in waste-water treatment plants and in receiving waters. Bacteriological, biological and limnological parameters of water quality and their measurement.

2513. TREATMENT PROCESSES

Credit 3 hrs. 3 Lect. Fall. Prerequisite, 2502 or equivalent. Analysis and design of processes for the removal of impurities from water and from municipal and industrial waste-water. Theoretical and applied aspects of treatment process design, including reaction kinetics, transfer phenomena, and the mechanics of fine particles.

2514. ASSIMILATION OF WASTES IN WATER

Credit 3 hrs. 3 Lect. Spring. Prerequisite, appropriate undergraduate course. Capacity of water resources to assimilate gaseous, liquid and particulate wastes. Phenomena pertinent to the dispersion and stabilization of wastes in water. Analog and digital computer methods. Emphasis on the advanced literature.

2515. WATER RESOURCE PROBLEMS

Credit 3 hrs. Lect.-Discuss. Fall. Open to engineers and non-engineers. A comprehensive approach to water resource planning and development. Historical and contemporary perspectives of water resource problems and policies.

2516. PHYSICAL BASIS OF WATER RESOURCE PLANNING

Credit 2 hrs. Lect.-Discuss. Fall. Intended primarily for non-engineering graduate students taking water resources as a minor subject. An introduction to hydrologic systems with topics in climate; surface and ground water flow; flood abatement and water quality control. Offers technical background material useful in subsequent courses in the water resources area.

2517. ENVIRONMENTAL SYSTEMS ENGINEERING I

Credit 3 hrs. 3 Lect. Fall. Prerequisite, permission of the instructor. Intended for graduate students but open to qualified undergraduates. Development and application of operations research and systems analysis techniques to the solution of civil, sanitary and other environmental engineering problems.

2518. ENVIRONMENTAL SYSTEMS ENGINEERING II

Credit 3 hrs. Spring. Prerequisite, permission of the instructor. Advanced topics in the analysis of water resource, sanitary engineering, and other environmental engineering systems. Taught as a seminar course by engineering and economics faculty.

2519. DESIGN OF SANITARY ENGINEERING SYSTEMS

On demand. Credit 3 hrs. Intended to give participants an opportunity to deal with actual design situations involving sewage systems, water distribution systems, and water and waste-water treatment systems.

2520. ENVIRONMENTAL HEALTH ENGINEERING

Credit 3 hrs. 3 Lect., Reports. Spring. Prerequisite, 2501, or equivalent, or permission of the instructor. Concepts of environmental health, principles of epidemiology and of toxicology. Introduction to radiological health. Consideration of problems in environmental control with emphasis on water quality control, air quality control and solid waste disposal.

2541. PROJECT. SANITARY ENGINEERING

On demand. Credit variable. Prerequisites, 2501 or 2502 or equivalent. The student will elect or be assigned problems in the design of water and waste-water treatment processes or plants; water distribution systems; waste-water disposal systems; water quality control systems; or of laboratory apparatus of special interest.

2542. SANITARY ENGINEERING RESEARCH

On demand. Credit variable. Prerequisites will depend upon the particular investigation to be undertaken. For the student who wishes to study a special topic or problem in greater depth than is possible in formal courses.

2543. SANITARY ENGINEERING SEMINAR

Credit 1–2 hrs. Fall-Spring. Required of all graduate students taking a major or minor in sanitary engineering; open to undergraduates by permission of instructor. Preparation, presentation, and discussion of topics and problems of current interest in sanitary engineering and water resources.

2545. WATER RESOURCE PLANNING SEMINAR (Also Economics 638)

Credit 3 hrs. Prerequisite, 2515. Spring. Case studies of multi-purpose river basin planning.

Transportation Engineering

Messrs. Belcher, Hewitt, Lewis, Liang, Slate.

2601. TRANSPORTATION ENGINEERING

Credit 3 hrs. Fall-spring. 2 Rec., 1 Lab. Transportation systems, traffic and operation, environmental investigations, transportation planning, highway engineering, other transportation modes, discussions of current issues. Staff.

2612. HIGHWAY LABORATORY – BITUMINOUS

Credit 3 hrs. Fall. 2 Lab., 1 Rec. Prerequisite, 2601, or may be taken concurrently with 2601. Physical, rheological, and durability properties of bituminous materials. Principles of the design of bituminous mixtures, including methods of test and the influence of aggregate, binder, test temperature, and rate of load application on the strength and flexibility of paving mixtures. Production of bituminous mixtures and construction practice. Laboratory fully equipped for all phases of applied and research studies. Mr. Hewitt.

2613. HIGHWAY LABORATORY – SUBGRADE SOILS

On demand. Credit 3 hrs. 2 Lab., 1 Seminar. Prerequisite, permission of instructor. Soil surveying, sampling, and classification. Correlation of field and laboratory procedures. Tests on soil samples stabilized with bituminous materials, Portland cement and chemicals. Condition surveys on stabilized roads. Evaluation of current practice and development. Laboratory fully equipped for all phases of applied and research studies. Mr. Liang.

2616. HIGHWAYS AND AIRPORTS

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 2601 or permission of the instructor. Part I: soil index properties and classification systems; subgrade strength evaluation; compaction; drainage and frost action; stabilization; aggregates. Part II: design and construction of base and surface courses for flexible pavements. Part III: design and construction of rigid pavements. Part IV: airport site selection; master plan; terminal facilities; heliports. Staff.

2618. LOW-COST ROADS

Credit 3 hrs. Primarily for foreign students. Offered upon sufficient demand, usually in fall term. Prerequisite, consent of instructor. Principally directed study with one 2½ hour class session per week to be arranged. Rural road systems as instruments of economic development. Study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces. Staff.

2621. ANALYSES AND INTERPRETATION OF AERIAL PHOTOGRAPHS

Preregistration required. Credit 3 hrs. Fall-spring. 2 Lect., 1 Lab. (The student is expected to pay the cost of field trips and aerial photographs for use in a term project, amounting to approximately $15.) A study of the soil and rock areas of the United States and the patterns present in aerial photographs. Fundamental elements of soil patterns are analyzed to permit determination of soil texture, type of bedrock, and drainage properties. Field training in selected test areas. Mr. Belcher.

2622. ADVANCED INTERPRETATION OF AERIAL PHOTOGRAPHS

Preregistration required. Credit 3 hrs. Fall-Spring. Course includes lectures and team projects in lab. and field. Facilities include material for city-regional planning, soil mapping, conservation, ground and surface water and civil engineering projects. Mr. Belcher.

2626. TRAFFIC ENGINEERING

Credit 3 hrs. Fall-spring. 2 Rec., 1 Lab. Prerequisite, permission of the instructor. City and highway traffic surveys and designs. Accidents, congestion, delay, speed, volume, density, parking, channelization, lighting, traffic control, and routing. Signs, signals, and markings. Urban traffic consideration in city planning. Driver reactions and habit pattern. Traffic engineering organization. Knowledge of simple programming procedures (CORC) desirable but not mandatory. Mr. Lewis.

2627. TRAFFIC ENGINEERING – OPERATIONS

On demand. Credit 3 hrs. 2 Lab., 1 Seminar. Prerequisite, preceded by or taken concurrently with 2626. Definition of traffic problems, collection of field data, analysis of field data, findings, conclusions, and recommendations. Traffic surveys. Design of traffic control systems. Mr. Lewis.

2628. HIGHWAY GEOMETRIC DESIGN

Credit 3 hrs. Spring. 1 Lect., 2 Lab. Prerequisite, 2601 or permission of the instructor. Route selection; design controls and criteria, including vehicle characteristics and highway capacity; sight distance, and horizontal and vertical control; cross section elements; right-of-way problems and access control; at-grade intersection design, including rotary and channelized intersection; grade separations and interchanges; regional systems of highways, freeways, and parkways. Mr. Lewis.

2631. PHYSICAL ENVIRONMENT EVALUATION

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Intended for graduate students or upperclassmen in engineering and planning. Permission of the instructor. A study of physical environment factors affecting engineering and planning decisions and the evaluation methods of these factors. Physical factors include the climate, soil and rock conditions, and water sources in different parts of the world. Evaluation methods include air and ground reconnaissance, interpretation of meteorological, topographic, geological, and soil maps, aerial photography, engineering data, and sub-surface exploration records. Mr. Liang.

2632. ADVANCED PHYSICAL ENVIRONMENT

On demand. Credit 3 hrs. Mr. Liang.

2641. TRANSPORTATION ENGINEERING PROJECT

On demand. Credit 1–6 hrs. Projects in the various fields of transportation, advanced aerial photographic studies, traffic engineering, and earth engineering may be developed by conference between professors and students. Projects may involve integrated planning or design, drawing upon several fields of interest, or they may concentrate upon special subjects. Adequate facilities, material, and sources of data are necessary for a satisfactory project.

2642. TRANSPORTATION ENGINEERING RESEARCH

On demand. Hours and credit variable. Students who wish to pursue one particular branch of transportation engineering further than can be done in any of the regular courses may elect work in this field. The work may be in the nature of an investigation of existing methods or systems, theoretical work with a view to simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

2643. TRANSPORTATION ENGINEERING SEMINAR

On demand. Credit 1–2 hrs. Number of meetings a week to be arranged. Abstraction and discussion of selected technical papers and publications in the transportation engineering field.

2644. TRANSPORTATION SPECIAL TOPICS

On demand. Credit varies.

Structural Engineering

Messrs. Errera, Fisher, Gergely, McGuire, Nilson, White, Winter.

2701. STRUCTURAL ENGINEERING I

Credit 3 hrs. Fall. 2 Lect., 1 2-hour period. Prerequisites, Mech. 212 and conc. reg. in Materials Science I. First course in a four-course sequence of structural theory, behavior, and design. Basic structural concepts. External forces on simple structures under fixed and moving loads. Properties of structural metals. Behavior under load of metal members (beams, compression members, and beam-columns), including elastic and inelastic buckling. Staff.

2702. STRUCTURAL ENGINEERING II

Credit 3 hrs. Spring. 2 Lect., 1 2-hour period. Prerequisite, 2701, Material Science I, and conc. reg. in Engineering Materials. Analysis of simple trusses under fixed and moving loads. Approximate analysis of building frames. Properties and behavior of reinforced concrete. Behavior under load of reinforced concrete beams, columns, and beam columns, including effects of prestressing. Computer applications to analysis and design. Staff.

2703. STRUCTURAL ENGINEERING III

Credit 3 hrs. Fall. 2 Lect., 1 2-hour period. Prerequisite, 2702, Engineering Materials. Elastic displacements. Analysis of statically indeterminate structures by classical and modern methods. Collapse theory and plastic design concepts. Applications to steel and concrete structures. Staff.

2704. STRUCTURAL DESIGN

Credit 3 or 4 hrs. Spring. 2 Lect., 1 or 2 2-hour periods. Prerequisite 2703. Comprehensive design project drawing on material from previous courses (2701–03). Additional design topics such as structural models, shell structures, connections, composite construction. Staff.

2710. STRENGTH OF STRUCTURES

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 2704; can be taken concurrently. Analysis of two- and three-dimensional stress and strain. Theories of failure of ductile and brittle materials. Microstructure of materials. Structural materials under load, strain hardening, Bauschinger effect residual stresses, hysteresis, stress concentration, brittle fracture, creep, alternating stress. Design for fatigue. Stresses beyond the elastic limit. Inelastic behavior of steel and reinforced concrete structures. Critical discussion of recent research and current design specifications. Mr. Winter.

2711. BUCKLING: ELASTIC AND INELASTIC

Credit 3 hrs. Spring. Prerequisite, 2710. Analysis of elastic and plastic stability. Determination of buckling loads and postbuckling behavior of columns. Solid and open web columns with variable cross-section. Beam columns. Frame buckling. Torsional-flexural buckling. Lateral strength of unbraced beams. Buckling loads and post-buckling strength of plates, shear webs, and cylindrical shells. Critical discussion of current design specification. Mr. Winter.

2712. ADVANCED STRUCTURAL ANALYSIS

Credit 2 or 3 hrs. Fall. 3 Lect. per week. Prerequisite 2703 or equivalent. Brief review of fundamental methods of analyzing hyperstatic structures and extension to complex structural systems. Real, virtual, and complementary work theorems. Elastic arch theory and design considerations. Curved beams, out-of-plane loading, grids, suspension systems, and other special structures. Plastic analysis.

2713. MATRIX STRUCTURAL ANALYSIS

Credit 3 hrs. Spring. 3 Lect. per week. Prerequisite 2712 or equivalent, short course in computer programming, and consent of instructor. The use of matrix algebraic methods of analysis of complex frameworks. Matrix formulation of generalized hyperstatic analysis, including generalized flexibilities of finite structural elements. Idealization techniques. Finite beam theory with applications to members on spring foundations, to secondary arch analysis, and to the analysis of suspension bridges. Use of digital computer (currently CDC 1604) for solution of problems.

2714. STRUCTURAL MODEL ANALYSIS AND EXPERIMENTAL METHODS

Credit 3 hrs. Fall or Spring. 2 Lect., 1 2-hr. period. Prerequisite, indeterminate analysis. Dimensional analysis and principles of similitude. Indirect model analysis of beams, frames, and trusses. Direct model analysis including loading and instrumentation techniques. Strain measurement and interpretation. Confidence levels for model results. Laboratory projects in elastic behavior and ultimate strength of model structures. Mr. White.

2715. NUMERICAL METHODS IN STRUCTURAL ENGINEERING

Credit 3 hrs. Fall. Prerequisite, differential equations, exposure to computer programming, and consent of instructor. Applications of numerical methods to structural problems, stressing solution by digital computer techniques. Solution of linear equation systems. Conventional numerical integration. Finite difference techniques for equilibrium and propagation problems. Newmark's Method. Eigenvalue determination. Other selected topics as time permits. Mr. White.

2716, 2717. BEHAVIOR AND DESIGN OF CONCRETE STRUCTURES

Credit 3 hrs. a term. Fall-spring. Prerequisite 2703 or equivalent. Analysis, design, and behavior of prestressed concrete and continuous reinforced concrete frameworks. Design of folded plate structures. Mr. Nilson.

2718 2719. BEHAVIOR AND DESIGN OF METAL STRUCTURES

Credit 3 hrs. a term. Fall-Spring. Prerequisite, 2703 or equivalent. Contemporary methods for analyzing and designing metal structures. Behavior of structural elements and frames. Selected design applications from the fields of steel plate structures, bridges, suspension systems, light weight structures. Mr. McGuire.

2720. SHELL THEORY AND DESIGN

Credit 3 hrs. Fall. Prerequisites, 1167, Math. 294 or equivalent, or consent of instructor. Classification of shells. Membrane and bending theory of shells. Applications to cylindrical shells, domes, paraboloids. Stability of certain types of shells and plate structures. Strength of stiffened shells. Mr. Gergely.

2722. DYNAMICS OF STRUCTURES

Credit 3 hrs. Spring. Prerequisites, Math. 294 or equivalent, and consent of instructor. Single degree of freedom systems. Equations of motion. Effects of damping. Natural frequencies. Forced vibration. Response spectra. Energy approach. Matrix formulation. Approximate solutions. Analysis of structures for ground disturbances. Mr. Gergely.

[2733. STRUCTURAL SYNTHESIS AND PLANNING

Not offered in 1965–66.]

2741. DESIGN PROJECT IN STRUCTURAL ENGINEERING

On demand. Hours and credit variable. The student may select a design problem such as an arch bridge, cantilever or rigid frame bridge, a special problem in steel or concrete building design, or the design of any other structure of particular interest to the student provided he has the proper preparation for such design. The work is submitted in the form of reports. Drawings of typical details must accompany reports.

2742. RESEARCH IN STRUCTURAL ENGINEERING

On demand. Hours and credit variable. Students wishing to pursue one particular branch of structural engineering further than can be done in any of the regular courses may elect work in this field. The prerequisite courses depend upon the nature of the work desired. The work may be in the nature of an investigation of existing types of construction, theoretical work with a view of simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

2743. STRUCTURAL ENGINEERING SEMINAR

Credit 1–3 hrs. Spring. Open to qualified seniors and graduate students. Preparation and presentation of topics of current interest in the field of structures for informal discussion.

2744. SPECIAL TOPICS IN STRUCTURAL ENGINEERING

On demand. Hours and credit variable. Individually supervised study in one or more of the specialized topics of civil engineering such as tanks and bins, suspension bridges, towers or movable bridges, which are not covered in the regular courses. Independent design or research projects may also be selected.

Special and Graduate Courses

2801. THESIS

The thesis gives the student an opportunity to work out a special problem or to make an engineering investigation, to record the results of his work, and to obtain academic credit for such work. Registration for thesis must be approved by the professor in charge at the beginning of the semester during which the work is to be done.

Individual courses may be arranged to suit the requirements of graduate students. They are intended to be pursued under the immediate direction of the professor in charge, the student usually being free from the restriction of the classroom and working either independently or in conjunction with others taking the same course.

Construction Engineering and Administration

Messrs. Blessis, Richards, and staff.

2901. CONSTRUCTION ENGINEERING

Credit 3 hrs. Fall. 3 Rec. Introduction to methods, equipment, and engineering principles and procedures involved in construction activities; major emphasis is on heavy construction such as large earth-moving projects, tunnels, caisson foundations, etc.; problems and oral reports by students based on current literature.

2902. LAW FOR ENGINEERS

Credit 3 hrs. Fall-spring. 3 Rec. Basic features of laws and practices relating to contracts, torts, agency, property, water rights, business organizations, sales, insurance, labor, governmental regulation of business, negotiable instruments, workmen's compensation, patents, ethical responsibilities of the engineer; term paper comparative analysis of the legal principles which affected the court decisions in some actual cases.

2903. ENGINEERING ECONOMY

Credit 3 hrs. Fall-spring. Principles and techniques for making decisions about the economic aspects of engineering projects: choosing between alternatives;

criteria for making decisions; time value of money; economic selection and operation; effect of income taxes; retirement and replacement; economy studies for government activities; introduction to estimating costs of construction.

2904. PUBLIC ADMINISTRATION

On demand. Credit 3 hrs. 3 Rec. Aspects of federal, state, and local government of interest to engineers, planners, constructors, and administrators: general principles of administration; patterns of government; the engineer's role in government; problems posed by our rapidly growing population and urbanization; regional public works projects; city and regional planning; codes; zoning; planning capital improvements; the city manager; managing and operating the engineering and other functions of municipalities.

2906. LEGAL PROBLEMS IN CONSTRUCTION

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 2902. An intensive investigation by the use of case material into the legal principles and practices affecting the work of the civil engineer in construction, particularly unknown site conditions, difficulties in construction, extensions of time, employer-employee relationships, liabilities of engineers and contractors to third parties, acquisitions of rights-of-way; detailed study of contract documents used in construction.

2907. CONSTRUCTION MANAGEMENT

Credit 3 hrs. Planning and operation of construction projects by the civil engineer: coordinated organizations and control of men, materials, and machines; scheduling; estimating; purchasing; selection and training of employees; operation and maintenance of equipment; cost control; accident prevention; and other topics. Special reports required.

2908. ENGINEERING PRACTICE

Credit 3 hrs. On demand. Prerequisite, fourth year or graduate standing. Analysis of large engineering works; planning and organizing engineering and construction projects; professional practice; feasibility evaluations; financial justification of projects; social and political implications. The case method will be used extensively. Dean Emeritus Hollister.

2941. PROJECT, CONSTRUCTION ENGINEERING AND ADMINISTRATION

Credit 3 hrs. On demand. Prerequisites, 2901, 2902, 2903, or permission. Development of a public or private engineering project selected by the student, involving economic analysis, planning, design, and construction procedures, with special emphasis on the legal, financial, and management aspects.

2942. CONSTRUCTION ENGINEERING AND ADMINISTRATION RESEARCH

On demand. Credit 3 hrs. Prerequisites, 2901, 2902, 2903, or permission. Investigation of special problems relating to the economic, legal, financial, and management aspects of public and private engineering operation of interest to the engineer-administrator, consulting engineer, and constructor.

2943. CONSTRUCTION ENGINEERING AND ADMINISTRATION SEMINAR

On demand. Credit 1–6 hrs. Prerequisites, (or concurrently), 2901, 2902, 2903, or permission. Guided study and discussions by small groups of selected students of topics which involve the legal, financial, and management aspects of civil engineering in public and private work, including discussions of current technical papers and publications.

MECHANICAL ENGINEERING

The courses in mechanical engineering are listed under the following headings: General, Engineering Design, Materials Processing, and Thermal Engineering.

General

3051. A.S.M.E. CORNELL UNIVERSITY SECTION

Credit 1 hr. Students who are entering the School of Mechanical Engineering are urged to become members of the Cornell University section of the American Society of Mechanical Engineers. The meetings of the Society, however, are open to all. Attendance at any twelve section meetings entitles the members to one hour elective credit; however, only one credit hour may be earned in this manner. Application for membership should be made in October of each year at the Mechanical Engineering office or to the faculty adviser of the student section, Mr. Wehe.

3053. MECHANICAL ENGINEERING LABORATORY

Credit 4 hrs. Fall. 1 Lect., 2 Lab. Prerequisites, 3322, 3622, 3623, and simultaneous registration in 3324 and 3625. Laboratory exercises in instrumentation, techniques and methods in mechanical engineering. Measurement of pressure, temperature, heat flow, mass transfer, displacement, force, stress, strain, vibrations, noise, etc. Use of electronic instruments and fast-response sensors for steady and transient states. Use of density-sensitive optical systems. Error analysis in experimental determinations. Staff.

3054. DESIGN OF MECHANICAL ENGINEERING SYSTEMS

Credit 4 hrs. Spring. 2 Lect., 2 Design Periods. Prerequisites, 3322, 3324, and 3625. Design experiences in the conception of machines and mechanical engineering systems. The determination of size from thermal or fluid-flow considerations. The conception of configuration from considerations of motion, strength, rigidity, and vibration. Selection of materials and mechanical components, including regard for thermal and corrosive environments. Design considerations for the processing of components, and their assembly. Feasibility studies and preliminary designs by sketches and layouts. Staff.

3055. ADVANCED MECHANICAL ENGINEERING DESIGN

Credit 3 hrs. Spring. 1 Lect., 2 Design Periods. Prerequisite, 3054 or equivalent. Intended for graduate students. Design of machines and mechanical systems. Similar to course 3054 but requiring the integration of engineering disciplines at an advanced level. Staff and guest lecturers.

3090. MECHANICAL ENGINEERING DESIGN PROJECT

Credit 3 hrs. Spring. Intended for students in the M.Eng.(Mech) program. Design of an engineering system or a device of advanced nature. Projects to be carried out by individual students or by small groups with individual assignments culminating in an engineering report by each student. Staff.

Engineering Design

Messrs. Abrahams, Baird, (on leave, spring 1966), Booker, Burr, DuBois, Ocvirk, Phelan, Wehe (on leave, fall 1965).

See also Courses 3054, 3055, 3090 under GENERAL above.

3115. CREATIVE SKETCHING

Credit 1 hr. Fall. 1 Lect. The sketch is the graphic tool of creative thought. Exercises to stimulate creative ability follow basic training of eye and hand for form awareness and sketching proficiency. Mr. Baird.

3116. INTRODUCTION TO INDUSTRIAL DESIGN

Credit 3 hrs. Fall. 2 Lab. Prerequisite, permission. Readings; abstract and applied design problems which investigate and apply the interrelationships existing between form, function, and materials. Mr. Baird.

[3117. INDUSTRIAL DESIGN

Credit 3 hrs. Fall. 2 Lab. Prerequisite, 3116. Readings and design problems. Readings integrate design with the contemporary social and economic scene. Design problems are directed toward creation of a comprehensive attitude in product development and toward attainment of a measure of design ability. Mr. Baird. Not offered in 1965–66.]

3190. SPECIAL INVESTIGATIONS IN INDUSTRIAL DESIGN

Credit based upon actual hours of work. Lab. as required. Fall. Mr. Baird.

3321. KINEMATICS AND DYNAMICS OF MECHANISMS

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Prerequisite, 212. Analysis of displacement, velocity, and acceleration in basic mechanisms for control, transmission, and conversion of motion and force. Cams, gears, and four-bar linkages. Forces associated with accelerated motion and gyroscopic action. The flywheel as a speed control device. Counter-balancing. Synthesis of mechanisms. Mr. Ocvirk.

3322. ANALYSIS AND DESIGN OF MACHINE COMPONENTS

Credit 3 hrs. Spring. 2 Rec., 1 Design period. Prerequisites, 3321, 6316, and 3431. A study of some major components of mechanical equipment such as clutches, brakes, gears, shafts, and bearings, with particular attention to performance characteristics, strength and durability, optimum proportions, and choice of materials. Design of castings and weldments. Stress-concentration. fatigue, residual stresses, and creep. Curved beams, pressure vessels, and rotors. Mr. Burr.

3323. DESIGN OF MACHINES

Credit 3 hrs. Spring. 1 Lec., 2 Design periods. Prerequisites, 3322, 3441. Methods for design and the stimulation of ingenuity. Contemporary design of machines in selected fields. Enclosures, lubrication, controls, and other requirements for a machine as a whole. Design considerations for processing and assembly. Feasibility studies and preliminary designs of mechanical systems. A more detailed design of one or more machines in the systems. Mr. DuBois. (Not offered after 1966.)

3324. VIBRATION AND CONTROL OF MECHANICAL SYSTEMS

Credit 3 hrs. Spring 1966. 3 Rec., 1 Lab.; beginning fall 1966. 2 Rec., 1 Lab. Prerequisite, 3321. Free, damped, and forced vibrations. Vibration isolation mounts, absorbers, and dampers. Control systems: the Laplace transform, transient response to specific inputs, transfer functions, frequency response, stability. Analog computer solutions. Laboratory on the vibration of machines and their components, balancing, and hydraulic and pneumatic control circuits. Modern instruments for measuring force and motion. Messrs. Phelan and Booker.

3331. KINEMATICS AND COMPONENTS OF MACHINES

Credit 3 hrs. Spring. 2 Lec.-Rec., 1 Comp. Prerequisites, 212 and 6311, or equivalents. May be elected by qualified students not in mechanical engineering. Theory and analysis of mechanisms and components based upon considerations of motion, velocity, acceleration, material, strength, and durability. Cams, linkages, couplings, clutches, brakes, belts, chains, gears, bearings, shafts, and springs.

3361. ADVANCED MECHANICAL ANALYSIS

Credit 3 hrs. Fall. 3 Rec. Intended for graduate students but open to qualified seniors. Prerequisite, 3322 or 3331. Advanced analysis of special clutches and brakes; theory of film-lubricated bearings; theories of failure and design equations; impact; simple and built-up cylinders subjected to pressure and rotation. Selected topics from advanced strength of materials. Thermal stresses and creep. Mr. Burr.

3362. MECHANICAL DESIGN OF TURBOMACHINERY

Credit 3 hrs. Spring. 3 Rec. Intended for graduate students. Prerequisites, 3361 and 3324. Mechanical design of major components of high speed compressors and turbines for structural adequacy and vibration-free operation. Selected topics from among the following: design of rotor components: disks, vanes, blades, shafts, and connections. Design of casing components: cylindrical, conical, torical shells; flat plates and diaphragms. Design of bearings, seals, gaskets, expansion members. Investigation of natural frequencies and critical speeds. Selection of materials. Attention is called to a companion course 3663. Mr. Ocvirk.

[3364. DESIGN FOR MANUFACTURE

Credit 3 hrs. Fall. 2 Rec., 1 Design Period. Prerequisites, 3322 or 3331, or permission of the instructor. Principles and methods of design to improve the producibility of machines, parts or products. Design techniques to simplify and speed the processing operations, to reduce cost, and to increase accuracy and product performance and reliability. Comparison of designs for small-lot and large-lot manufacture. Exploitation of the capabilities inherent in machine tools and other production machines. Jigs and fixtures. Applications of the foregoing by design exercises. Mr. DuBois. Not offered in 1965–66.]

3366. ADVANCED KINEMATICS

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Prerequisite, 3321. Advanced analytical and graphical determination of velocities and accelerations in mechanisms. Special geometrical concepts on the kinematics of mechanisms. Synthesis of linkages by graphical and analytical methods. Design of linkages to give prescribed paths, positions, velocities, and accelerations. Mr. Ocvirk.

3368. MECHANICAL VIBRATIONS

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Intended for graduate students but open to qualified seniors. Prerequisite, 3324 or equivalent. Further development of vibration phenomena in single and multi-degree of freedom systems, with emphasis on engineering problems involving analysis and design. Also gyroscopic effects, branched systems, random vibrations, impact and transient phenomena, isolation of shock and vibration, and noise and its reduction. Impedance, matrix, and numerical methods. Analog and digital computer solutions and laboratory studies. Mr. Burr.

3372. EXPERIMENTAL METHODS IN MACHINE DESIGN

Credit 3 hrs. Fall. 1 Rec., 2 Lab. Prerequisite, 3322 or 3331. Investigation and evaluation of methods used to obtain design and performance data. Techniques of photoelasticity, strain measurement, photography, vibration and sound measurements, balancing methods, and development techniques are studied as applied to machine design problems. Mr. Phelan.

3374. CONCEPTUAL DESIGN

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3322 or equivalent. Conception and initial design of products and machines. Methods to stimulate mechanical ingenuity and improve appearance. Principles of synthesis and creativity employing association, inversion, and other techniques. Sketching, class discussion, and comparative evaluation of solutions. Mr. DuBois.

3375. AUTOMATIC MACHINERY

Credit 3 hrs. Spring. 2 Rec., 1 Field trip. Prerequisite, 3321. A study of automatic and semiautomatic machinery such as dairy, canning, wire-forming, textile, machine-tool, computing, and printing equipment. Mr. Wehe.

3377. AUTOMOTIVE ENGINEERING

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3322. Analysis of various designs for the parts of an automotive vehicle, other than the engine, in relation to its performance; stability, weight distribution, traction, steering, driving, braking, riding comfort, power required and available, transmission types, acceleration, and climbing ability. Recommended together with Course 3670 for a study of automotive engineering. Mr. Dubois.

3378. AUTOMATIC CONTROL SYSTEMS

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Intended for graduate students but open to qualified seniors. Prerequisite, 3324 or equivalent. Further development of feedback control theory, including stability criteria, frequency response, and transfer functions, with emphasis on engineering problems involving the analysis of existing control systems and the design of systems to perform specified tasks. Also, non-linear systems, describing functions, sampled-data systems, and compensation techniques. Analog computer simulation and laboratory studies of hydraulic, pneumatic, and electro-mechanical components and systems.

3380. DESIGN OF COMPLEX SYSTEMS

Credit 3 hrs. Spring. Two meetings of 2 hours per week to be arranged. Intended for graduate students in engineering. Permission of professor in charge. A seminar course relying heavily on student participation in discussing frontier problems such as salt water conversion, transportation devices and systems, systems for space and underwater exploitation. Determination of specifications for these systems to meet given needs. Critical discussion of possible solutions based on technical as well as economic and social considerations. Reports will be required containing recommendations and reasoning leading to these considerations.

3390. SPECIAL INVESTIGATIONS IN MACHINE DESIGN

Permission of department head required. Credit arranged. Either term. Individual work or work in small groups under guidance in the design and development of a complete machine, in the analysis of experimental investigation of a machine or component of a machine, or studies in a special field of machine design. Staff.

3391. MACHINE DESIGN SEMINAR

A one-and-a-half hour meeting approximately every other week. Required of graduate students majoring in machine design. Discussion and study of topics of importance in the field by faculty, graduate students, and outside speakers. Mr. Burr.

3392. SPECIAL TOPICS IN ENGINEERING DESIGN

Credit 1 hr. or more. Either term. 10–15 lecture periods per term on a topic of special interest not requiring a course of standard length. Series of lectures by staff members or visiting staff on subjects of current interest; topics announced prior to beginning of term. Hours to be arranged to suit. More than one topic may be taken if offered. Department to be consulted before registration.

Materials Processing

Messrs. Carpenter, Dispenza, Geer, Morgan.

3431. MATERIALS PROCESSING

Credit 3 hrs. Fall. 1 Lect., 2 Lab. Comprehensive studies of materials and machinery involved in material removal. Energy transfer and environment aspects. Mechanics of chip formation and removal. Cutter materials and geometry. Force, deformation, and power relationships. Single, multiple, and multi-tooth tool capabilities. Ultrasonic, electrical discharge, electro-chemical, and other "non-chip" removal processes. Process planning for fixed and flexible programming. Thread and gear manufacturing. Basic metrology. Gaging principles for fixed and comparative systems using mechanical, electrical, optical, pneumatic, or radiation type devices. Surface texture determination. Quality control systems. Mr. Geer.

3441. MATERIALS PROCESSING

Credit 4 hrs. Fall. 2 Lect., 2 Lab. Prerequisite, 6316. Concepts of manufacturing process involving material removal, materials, energy levels, environment, and topological considerations. Physics and mechanics of chip formation, plastic deformation, force and power relationships. Tool temperature and tool wear studies. Machinability of materials. Single, multiple and multi-point cutting tool capabilities. General purpose and production machine tools employed in tool planning. Fixed and flexible — programmed automated equipment. Ultrasonic, electrical discharge machining, electro-chemical machining and other non-chip removal processes. Basic metrological principles. Principles of gaging using fixed and comparative instruments of mechanical, electrical, optical, pneumatic or radiation type. Quality assurance and surface texture determination. Mr. Geer. (Not offered after Fall 1965.)

3451. MATERIAL REMOVAL SYSTEMS

Credit 3 hrs. Fall. 1 Lect., 2 Lab. Prerequisites, 3431, 6316. For graduate students and qualified undergraduates. Advanced study of mechanics of chip formation. Forces and power dynamometry. Friction and surface chemistry. Thermal aspects. Piispanen's model, Ernst-Merchant analysis. Orthogonal and three-dimensional relationships. Cutter geometry and chip control. Energy transfer systems and removal rates. Non-chip techniques using chemical, electrical, ultrasonic, and other media; surface characteristics; and post-process treatments. Mr. Geer.

3461. QUALITY ASSURANCE SYSTEMS

Credit 3 hrs. Fall-spring. 2 Lect., 1 Lab. Prerequisites, 3431, 9170. For graduate students and qualified undergraduates. Theory and computational techniques for control by attributes or variables. Methods for making machine tool capability studies, instrumentation systems. Standards codes and applications. Metrological equipment performance characteristics. Fixed and comparative gaging systems; non-contact, reflective, and radiation principles. Surface texture phenomena. True-position tolerancing and charting. Corrective action procedures. Mr. Geer.

3471. PRODUCT ENGINEERING FOR MANUFACTURE

Credit 3 hrs. Fall. 1 Lect., 2 Lab. Prerequisites, 3431, 6316. For graduate students and qualified undergraduates. Detailed and intensive study of component configuration for fixture constraint and tooling sequence. Cutting tools and holder designs. Economics of lot size and processing parameters. Non-machining elements of processing cycles. Pre-production and post-production analyses, process planning, machine capabilities and selection. Integrated machines, transfer concepts, automated equipment. Fixed-program capabilities. Mr. Geer.

3475. NUMERICAL CONTROL OF PROCESSES

Credit 3 hrs. Spring. 2 Lect., 1 Lab.-Comp. Prerequisites, 3431, 3471. For graduate students and qualified undergraduates. A thorough study of concepts, systems, and component designs for flexible-programmed processing. Manufacturing advantages and limitations. Manufacturing functions under numerical control. Machine tools as related to numerical control. Specialized process applications. Tooling concepts, presets, changeover devices. Machine command-response factors, stick-slip, resonance, shaft windup, mass-inertia and other effects. Positioning control systems and coding. Straight cut and contouring systems. Manual and computer programming. Optimizing numerical control manufacturing. Simulation studies. Mr. Geer.

3490. SPECIAL INVESTIGATIONS IN MATERIALS PROCESSING

Credit and hours as arranged. Discussion and study of selected topics on theory of metal cutting and working processes, the technology of manufacture with machine tools, and metrology and production gaging; topics and assigned study to suit individual needs. Mr. Geer.

3498, 3499. PROJECT

Total credit 6 hrs. Intended for graduate students. Work in the form of projects to integrate the training in mechanical engineering when such work is done principally in the field of materials processing. Mr. Geer.

Thermal Engineering

Messrs. Barrows, Conta, Dropkin, Erdman, Fairchild, Gebhart, McManus, Moore, Pierce, Shepherd.

3621. THERMAL SCIENCE I: THERMODYNAMICS

Credit 3 hrs. Fall. 3 Rec. Prerequisites, Math. 294, Physics 224. The definitions, concepts, and laws of classical thermodynamics. Applications to homogeneous systems and control volumes. Potential functions, maximum work, availability, and irreversibility. Maxwell's relations and general thermodynamics functions. Entropy and thermodynamic probability. Ideal gases, gas processes, and variable specific heats.

3622. THERMAL SCIENCE II: THERMODYNAMICS

Credit 2 hrs. Spring. 2 Rec. Prerequisite, 3621 or equivalent. Thermodynamic properties of multiphase pure substances and real gases. Non-reactive mixtures, reactive systems, combustion. Chemical equilibrium and chemical potential; applications to combustion. Heat engine and heat pump cycles. Introduction to irreversible thermodynamics; applications.

3623. THERMAL SCIENCE III: FLUID MECHANICS

Credit 4 hrs. Spring. 4 Rec. Prerequisites, Mechanics 212, 3621. Properties of fluids, fluid statics; kinematics of flow, stream function, velocity potential, elements of hydrodynamics; dynamics of flow, momentum and energy relations, Euler equations, wave motion; thermodynamics of flow, stagnation values, Mach number relationships; dimensional analysis; real fluid phenomena, laminar and turbulent motion; flow in ducts, universal velocity distribution; compressible flow with area change, friction and heating, normal shock; flow over immersed bodies, laminar and turbulent layer, exact and momentum solutions; lift and drag; elements of two-dimensional compressible flow, expansion waves, oblique shock. Mr. Shepherd.

3624. THERMAL SCIENCE IV: LABORATORY

Credit 3 hrs. Fall. 2 Labs. Prerequisites, 3622, 3623, and simultaneous registration in 3625. Laboratory exercises and demonstrations related to thermodynamic, fluid mechanic, and diffusion transport phenomena. Combustion, direct energy conversion. Fluid flow circumstances, stability, and regimes. Spectral distribution effects in radiation. Transport properties. Laminar and turbulent transport. Mass transport. Demonstration of fast response sensors, spectral analysis, and of density sensitive optical systems. Use of electronic instrumentation. Analysis of error in experimental determinations. Mr. Gebhart. (Not offered after Fall 1965.)

3625. THERMAL SCIENCE V: HEAT TRANSFER

Credit 3 hrs. Fall. 1 Lect., 2 Rec. Prerequisites, 3622, 3623. Conduction of heat in the steady state, unsteady state and periodic heat flow; analogic methods; numerical methods; systems with heat sources. Convection: boundary layer fundamentals; natural convection; forced convection inside tubes and ducts; forced convection over various surfaces. Boiling and condensation. Radiation: emission, absorption, reflection, transmission, and exchanges. Radiation combined with conduction and convection. Heat exchangers: overall heat transfer coefficients; mean temperature difference; effectiveness; design. Mr. Dropkin.

3626. THERMAL SYSTEMS ENGINEERING

Credit 4 hrs. Spring. 2 Lects., 1 Lab. Prerequisites, 3622, 3623, 3053, 3625. Applications of thermodynamics, fluid mechanics, and heat transfer to complete thermal systems rather than to processes. Work-producing, heat-producing, heat-pumping, propulsion, and environmental control systems. Classification, criteria of performance, and economic considerations. Steam power plants, combustion engines, refrigerating systems, air conditioning systems, fuel cells, thermo-electric cooling and power generation. Mr. McManus.

3630. ENGINEERING THERMODYNAMICS

Credit 3 hrs. Fall. 3 Rec. Laws of thermodynamics; energy equations; thermodynamic properties of state of gases and vapors, nonflow and flow processes; gas and vapor cycles; refrigeration; mixtures of air and water vapor. (Not intended for students in Mechanical Engineering.)

3631. ENGINEERING FLUID MECHANICS

Credit 3 hrs. Spring. 3 Rec. Prerequisites, Mechanics 212, 3630. Brief treatment of hydrostatics, kinetics and dynamics of flow; momentum and energy relations. Thermodynamics of flow; wave motion; stagnation properties. Real flow phenomena, laminar and turbulent motion. Pipe flow; compressible flow with area change, normal shock; nozzle flow. Dimensional analysis. Flow metering. Flow over immersed bodies; boundary layer; lift and drag. Elements of turbomachinery; turbomachine characteristics; turbomachine components in couplings and torque converters. (Not intended for students in Mechanical Engineering.)

3633. ENGINEERING THERMODYNAMICS AND HEAT TRANSFER

Credit 3 hrs. Spring. 3 Rec. Laws of thermodynamics; energy equations; thermodynamic properties of state of gases and vapors; processes; gas and vapor cycles of heat engines and heat pumps; introduction to heat transfer by conduction, convection, and radiation; heat transfer in engineering equipment by combined modes. (Not intended for students in Mechanical Engineering.)

[3651. ADVANCED THERMAL SCIENCE

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623, 3625, or equivalent. Intended for graduate students in the M.Eng.(Mech) program. Advanced level study of topics from thermodynamics, fluid mechanics, and heat transfer. Selection of subjects from irreversible thermodynamics, statistical mechanics, real gas behavior, chemical thermodynamics, unsteady flow phenomena, gas dynamics, shock tube analysis, turbulent flow of jets and wakes, compressible boundary layer, numerical methods, variable properties and step changes in heat transfer, mass transfer. Not offered in 1965–66.]

3652. COMBUSTION THEORY

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 3625. Intended for graduate students and qualified fifth year students. Application of the basic equations of fluid flow and heat and mass transfer to homogeneous and diffusion flames. Ignition, quenching, rate processes, and dissociation effects will be examined. Consideration will be given to flame stabilization and practical systems. Mr. McManus.

3653. REFRIGERATION

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3625 or 3625 concurrently. Introduction to refrigeration with emphasis on application of thermodynamics, fluid dynamics and heat transfer. Cycle and component performance. Applications in air conditioning and cold storage. Overall performance under varied operating conditions. Cryogenic refrigeration; gas liquefaction, purification, storage, and special heat transfer problems. Thermoelectric cooling. Mr. Fairchild.

3654. AIR CONDITIONING

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3625 or 3625 concurrently. Introduction to air conditioning with emphasis on application of thermodynamics, fluid dynamics, mass transfer and heat transfer. Psychrometrics, air conditioning processes and cycles. Heat transmission in buildings; solar effects; lumped thermal circuit methods. Heat pumps. Air distribution. Component and system performance. Mr. Fairchild.

3657. THERMAL POWER PLANTS

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3625. Introduction to steam power plants with emphasis on application of thermodynamics, fluid mechanics, and heat transfer to important components such as steam generating units, turbines, condensers, pumps, blowers, etc. Consideration is given to fossil fuels and nuclear reaction as sources of energy. Mr. Erdman.

3661. ADVANCED THERMODYNAMICS I

Credit 3 hrs. Fall. 3 Lect. Intended for graduate students but open to qualified undergraduates. Prerequisites, 3621, 3622, or equivalent. A rigorous and general treatment of classical thermodynamics with emphasis on mathematical developments and philosophical interpretations. The several statements of the concepts and laws of thermodynamics and equivalence proofs, the pure substance, homogeneous and heterogeneous systems. Potential functions and Maxwell's relations, availability, irreversibility, and equilibrium. Entropy flow, entropy production, and irreversible thermodynamics. The relationship between classical thermodynamics, classical statistics, quantum statistics, and information theory. Mr. Conta.

3663. TURBOMACHINERY

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623, or permission of instructor. Aerothermodynamic design of turbomachines in general, followed by consideration of specific types; fans, compressors, and pumps; steam, gas, and hydraulic turbines. Energy transfer between a fluid and a rotor; flow in channels and over blades. Compressible flow, three-dimensional effects, surging and cavitation. Outline design of a high-performance compressor-turbine unit. Mr. Shepherd. Attention is drawn to 3362 as a companion course for mechanical design.

3664. INTERMEDIATE FLUID MECHANICS

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3623. Integrated development of equations of mass, motion, and energy for fluid particles and control volumes. Applications of these governing relations to various selected areas such as hydrodynamics and conformal transformations in ideal flows; laminar and turbulent flows; boundary layers with energy transfer; two-dimensional compressible flows; variable property flows; unsteady one-dimensional flows; other topics of current interest. Mr. Pierce.

3665. TRANSPORT PROCESSES

Credit 3 hrs. Fall. 3 Rec. For graduate students and advanced undergraduate students. Prerequisites, basic thermodynamics and fluid mechanics. Description of basic microscopic modes of thermal and mass diffusion. Molecular transport mechanics in gases. Formulation of the transport equations and their application to engineering problems. Conduction and mass diffusion in solids, boundary value problems. Thermal radiation between opaque surfaces in vacuum and as a diffusion process in non-opaque media. Mass and energy diffusion by molecular and by eddy processes in convection. Analytical methods in convection investigated, limits shown, and the role of correlations discussed. Analogous phenomena. Combined mode heat transfer. Mr. Gebhart.

3667. ADVANCED THERMAL ENGINEERING MEASUREMENTS I

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Intended for graduate students but open to qualified undergraduates. Prerequisite, 3625. Theory, construction, calibration, and application of liquid-in-glass thermometers, solid expansion thermometers, pressure-spring thermometers, resistance thermometers, thermoelectric thermometers, optical pyrometers, radiation pyrometers, enthalpy probes, heat flux probes. Mr. Dropkin.

3669. COMBUSTION ENGINES I

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623, 3625. Introduction to combustion engines with emphasis on application of thermodynamics, fluid dynamics, and heat transfer; reciprocating combustion engines; gas turbines; compound engines; reaction engines. Mr. Fairchild.

3670. COMBUSTION ENGINES II

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3669 or equivalent. Advanced study of topics in field of reciprocating engines, both spark-ignition and diesel. Methods of thermodynamic analysis and performance prediction for free-piston power plants and supercharged engines. Relation of engine performance characteristics and performance characteristics of automotive vehicles. Recommended together with Course 3377 for study in automotive engineering. Mr. Fairchild.

3671. AEROSPACE PROPULSION SYSTEMS

Credit 3 hrs. Spring. 3 Rec. Prerequisites, 3622, 3623, or permission of instructor. Intended for graduate students and qualified undergraduates. Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion. Mr. Shepherd.

3672. ENERGY CONVERSION

Credit 3 hrs. Spring. 3 Lect. Intended for graduate students but open to qualified undergraduates. Prerequisite, 3622 or equivalent. Primarily an analysis of energy conversion devices from a classification into heat engines, chemical engines, and expansion engines. An analysis of each class from the point of view of efficiency and other criteria of performance. A more detailed study of some conventional and some direct energy conversion devices including thermoelectric, thermionic, and photovoltaic converters; and fuel cells. Energy sources and energy storage, applications to terrestrial and space power systems.

3673. ADVANCED THERMAL ENGINEERING MEASUREMENTS II

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Intended for graduate students but open to qualified fifth year students. Theory and operation of instruments used in fluid flow investigations; hot wire anemometers; density-sensitive optical systems, transient temperature and pressure measurements; measurements in reacting systems; error analysis and treatment of data. Mr. McManus.

3674. ADVANCED THERMODYNAMICS II

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623. Fundamental equations of kinetic theory through Maxwell's transport relation. Microscopic transport equations of mass, motion, and energy. The concepts of pressure and temperature in viscous heat conducting gases. Maxwell-Boltzmann statistics and quantum statistics in the classical limit. Phenomonological transport and thermodynamic properties in ideal, inert, and reacting gaseous systems. Equilibrium dissociating and ionized flows. Introduction to non-equilibrium flows. Mr. Pierce.

3680. ADVANCED CONVECTION HEAT TRANSFER

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3665 or consent of instructor. Processes of transport of thermal energy, momentum, and mass in fluids are considered in detail. Theories of transfer processes and analytic solutions. Analytical and experimental results compared. Transport equations for a fluid, delineation of kinds of processes, differential similarity, natural convection, forced convection at low and high velocities. Boundary layer solutions, similarity theories, and effects of turbulence. Transport in rarefied gases. Mr. Gebhart.

3681. ADVANCED CONDUCTION AND RADIATION HEAT TRANSFER

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3665 or consent of instructor. Theories of conduction mechanisms. The conduction of heat in solids under conditions of steady, unsteady, and periodic heat flow with and without internal sources. Mathematical, numerical, and analog methods of problem solution are considered. The various types of thermal radiation processes in solids and gases. Spatial and specular distribution of radiation. Methods of calculation for radiation in the absence and in the presence of absorbing and emitting gases. Mr. Gebhart.

3682. SEMINAR IN HEAT TRANSFER

Credit 3 hrs. Spring. Two meetings of 2 hours per week to be arranged. Prerequisite, permission of professor in charge. Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions. Mr. Gebhart.

3683. VISCOUS FLOW THEORY

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3664 or permission of instructor. Intended for graduate students. Stress and rates of deformation tensors, derivation of the Navier-Stokes equations. Exact solutions, very slow motion, boundary layers, Tollmien-Schlichting and Taylor instability, turbulence. Mr. Barrows.

3690. SPECIAL INVESTIGATIONS IN THERMAL ENGINEERING

Fall-spring. Credit by arrangement. Intended either for informal instruction to a small number of students interested in work to supplement that given in regular courses or for a student to pursue a particular investigation outside of regular courses. Permission of the department required for registation. Mr. Shepherd.

3691. THERMAL ENGINEERING SEMINAR

No credit. A one-and-a-half-hour meeting approximately every other week. Attendance expected of all graduate students with major subject in the Department of Thermal Engineering. Talks by graduate students, staff members, and invited guests.

3692. SPECIAL TOPICS IN THERMAL ENGINEERING

Credit 1 hr. or more. Either term. 10–15 lecture periods per term on a topic of special interest not requiring a course of standard length. Series of lectures by staff members or visiting staff on subjects of current interest, topics announced prior to beginning of term. Hours to be arranged to suit. More than one topic may be taken if offered. Department to be consulted before registration. Mr. Shepherd.

ELECTRICAL ENGINEERING

Required Courses

SYSTEMS SEQUENCE

4301. LINEAR PASSIVE NETWORKS

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisite, Electrical Science 242 or 244, or equivalent. Analysis of RLC networks with exponential excitations; emphasis on the sinusoidal steady state; orderly and exact procedure for solving complex linear network problems stressing understanding of the physical significance of all solutions; matrix methods; limitations of physical networks; synthesis of periodic signals by Fourier series.

4302. INTRODUCTION TO ACTIVE SYSTEMS

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, 4301. Analysis and design of systems with linear and nonlinear, passive and active elements; analytical and graphical techniques. Amplifiers, oscillators, electromechanical transducers, and modulators; equivalent circuits; concepts of energy balance;

feedback and stability; application to instrumentation, control, electromechanical energy conversion, and communication.

4401. LINEAR SYSTEMS ANALYSIS

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisite, 4301. Analysis of linear systems subjected to arbitrary excitations. Fourier, double-sided Laplace, and z-transforms by contour integration in the complex plane; frequency-domain analysis by transforms; time-domain analysis by the convolution integral; relationship of time- and frequency-domain analyses, s-plane transformations; singularity functions applied to signal synthesis and the representation of initial conditions.

4402. ACTIVE SYSTEMS

Credit 4 hrs. Spring. 3 Lect., 1 Rec. Prerequisites, 4302 and 4401. Analysis of systems containing passive elements and controlled sources. Formal methods; matrix analysis of interconnected linear models; flow graphs and analog simulation; methods for determining stability; system-parameter sensitivity and feedback; signal generation; filter synthesis; compensating networks; physical realizability; linear time-variable networks. Emphasis on the physical and mathematical understanding required to achieve desired system behavior.

4501. SYSTEMS WITH RANDOM SIGNALS

Credit 4 hrs. Fall. 3 Lect. 1 Rec. Prerequisite, 4402. Modulation theory; basic principles of AM and FM; introduction to random signals; heuristic development of random variables and processes; statistical and time averages; analysis of linear systems with random excitations; noise in physical systems; optimization techniques; filtering; prediction; compensation; matched systems.

4502. STATISTICAL ASPECTS OF SYSTEM ANALYSIS

Credit 4 hrs. Spring. 3 Lect. 1 Rec. Prerequisite, 4501. Development of statistical concepts and their application to system problems. Sampling; estimation of parameters; regression; hypothesis testing. Basic elements of information theory with application to various transmission systems.

ELECTROPHYSICS SEQUENCE

4311. ELECTROMAGNETIC WAVES

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisites, Electrical Science 242 or 244, and Mathematics 294. Foundations of electromagnetic theory for propagation and radiation of electromagnetic waves; Maxwell's equation; transmission lines; one-dimensional waves; plane waves; oblique reflection; guided waves, strip-line and rectangular wave guide; radiation; elementary antenna concepts.

4312. APPLIED THERMODYNAMICS

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisites, 4311, Chemistry 276, and Physics 224. Brief review and applications of general laws of thermodynamics to gases. Elements of one-dimensional compressible-gas dynamics, channel flows, shock waves, and applications in flow systems; elements of kinetic theory, a derivation of the Navier-Stokes equations and Boltzmann's equation; quantum statistics applied to heat capacities, chemical reactions, and ionized gases; basic formulation of fluid plasma equations and waves in the plasma.

4411. QUANTUM THEORY

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisite, 4312. Introduction to non-relativistic quantum theory; experimental basis for wave-particle duality; structure of the theory in terms of wave functions; operators, and matrix elements; solution of Schroedinger's equation for one- and three-dimensional potentials; angular momentum; perturbation theory; spin; interaction of atoms with static and radiation fields; central field model of atomic structure and the Pauli exclusion principle, quantum statistics; structure of crystalline solids.

4412. SOLID-STATE PHYSICS

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, 4411. Introduction to solid-state physics based on quantum theory; binding in ionic and covalent crystals; free electron theory of metals with application to electrical conductivity and electron emission; band theory of solids; semiconductor theory including application to p-n junction devices; dielectric properties of solids; magnetism; super-conductivity.

4511. ELECTRODYNAMICS

Credit 4 hrs. Fall. 3 Lect., 1 Rec. Prerequisites, 4312, 4402. Static fields; electromagnetic stresses, forces and torques; quasi-stationary fields, eddy currents; electromechanical energy conversion; traveling waves generated by distributed currents; transformation to moving reference frames, unipolar induction; interaction of fields with rigid and fluid conductors in motion; interaction of fields with charged particles and plasmas; transport processes in plasmas.

4512. FIELDS, WAVES AND ELECTRONS

Credit 4 hrs. Spring. 3 Lect., 1 Rec. Prerequisites, 4412, 4511. Electromagnetic fields and waves in metal and dielectric wave guides and cavities; plasmas and electron-beam generation; fields and waves in stationary and moving plasmas, coupling of modes of wave propagation; sources of electronic noise.

LABORATORY SEQUENCES

4321. ELECTRICAL LABORATORY I

Credit 4 hrs. Fall. 1 Lect., 2 Lab. Basic instrumentation and electrical measurements involving circuits and fields of passive electrical elements; elementary mechanical and electrical resonant circuits; and an experimental introduction to physical electronics.

4322. ELECTRICAL LABORATORY II

Credit 4 hrs. Spring. 1 Lect., 2 Lab. Basic experiments concerning parallel wire transmission lines; energy conversion methods; amplifiers and oscillators; high vacuum techniques; and fundamental properties of plasmas.

4421. ELECTRICAL LABORATORY III

Credit 4 hrs. Fall. 1 Lect., 2 Lab. Advanced experiments concerning wave composition and shaping; analog computers; modulation; interaction of rotating and traveling electromagnetic waves with solid and fluid conductors; high frequency properties of dielectrics; high frequency properties of plasmas; and reflection, refraction, and scattering of radio waves.

4422. ELECTRICAL LABORATORY IV

Credit 4 hrs. Spring. 1 Lect., 2 Lab. Advanced experiments concerning filters; feedback amplifiers; multivibrators; parametric amplification, noise; drift, diffusion and recombination of carriers in semiconductors; internal fields and spontaneous polarization; magnetic resonance; and physical properties of C.W. optical gas masers.

Elective and Graduate Courses

Of the following elective and graduate courses, certain ones may not be offered every year if the demand is considered to be insufficient. For the courses that follow, the digits in the four-digit course number have significance as follows (see page 48).

SEMICONDUCTOR AND QUANTUM ELECTRONICS

4531. QUANTUM ELECTRONICS I

Credit 3 hrs. Fall. 3 Lect. Prerequisites, Physics 325–326 or 4311, and Physics 443 or 4412. A detailed treatment of the physical principles underlying masers and lasers. Topics will include the interaction of radiation and matter; quantum properties of an electromagnetic radiation field; the coherence properties of spontaneous and stimulated emission of radiation; theory of partial coherence; thermal equilibrium and non-equilibrium in paramagnetic systems; quantum theory of angular momentum with application to atomic structure; properties of paramagnetic ions in crystals.

4532. QUANTUM ELECTRONICS II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, Quantum Electronics I or consent of instructor. A continuation of the treatment of the physical principles underlying maser devices. Topics will include the analysis of solid state and gaseous masers and lasers including the methods used to obtain state inversion; operating characteristics of the most important of these devices; semi-conductor injection lasers; nonlinear processes such as double quantum absorption, harmonic generation, photomixing; applications of masers and lasers.

4533. SEMICONDUCTOR ELECTRONICS I

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, 4412. The physical theory of p-n junction devices; device fabrication; properties of semiconductor devices such as diodes and rectifiers, tunnel diodes, solar batteries, transistors, four-layer devices (diodes, controlled rectifiers and switches), etc.; device equivalent-circuit representations; bias-stabilized transistor amplifiers.

4534. SEMICONDUCTOR ELECTRONICS II

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, 4533. A continuation of Semiconductor Electronics I with emphasis on the application of semiconductor devices as active or passive elements in circuits for use as power supplies, power controls, amplifiers, oscillators and multivibrators, pulse circuits, gates and switches, etc.; integrated circuits; parametric amplification.

4535. INFRARED AND OPTICAL PROPERTIES OF SOLIDS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4412 or Physics 454 or consent of instructor. Macroscopic dielectric properties of solids: complex permittivity and permeability, Fresnel equations, reflection and refraction by lossless and lossy media, anisotropic dielectric constant tensor, rotation and deflection of radiation by electro-optic crystals; Microscopic formulation of dielectric properties; electronic, atomic and orientation polarization, dielectric dispersion via resonance or relaxation, local internal field and spontaneous ordering, introductory lattice dynamics, lattice frequency spectrum, application of group theory to derivation of selection rules for infrared and Raman active normal modes. Extended-frequency analysis of vibrational spectra with applications to ferroelectrics.

POWER SYSTEMS AND MACHINERY

4441. CONTEMPORARY ELECTRICAL MACHINERY I

Credit 3 hrs. Fall. 2 Lect.-Rec., 1 Lab.-Comp. Prerequisite, 4302. Emphasis on engineering principles. Real and reactive power requirements of core materials with symmetrical and with biased magnetizing forces; analysis and characteristic prediction of high-efficiency transformers; magnetic amplifiers, energy transfers among electric circuits, magnetic fields and mechanical systems; control of magnetic field distribution by reluctance and winding distribution; travelling fields from polyphase excitation; elementary idealized commutator-type, asynchronous, and synchronous machines.

4442. CONTEMPORARY ELECTRICAL MACHINERY II

Credit 3 hrs. Spring. 2 Lect.-Rec., 1 Lab.-Comp. Prerequisite, 4302. Emphasis on engineering principles. Production of air-gap magnetic fields; elementary and idealized rotating machines; steady-state and transient characteristics of realistic rotating machines; a-c commutator-type single-phase motors; polyphase synchronous, and single phase induction machines; recently developed types: Saturistor motor, self-excited a-c generators; miscellaneous rotary devices; Hysteresis motor, selsyns, amplidynes, frequency converters.

4443. POWER SYSTEM EQUIPMENT

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisite, 4302. System equipment and control parameters are studied. Test requirements for electrical apparatus for conventional and nuclear electrical power production and distribution are considered. Prime movers, generators and their accessories, switchgear, protective devices, power transformers, converters, towers, conductors, regulating devices, and data gathering and computer control systems are analyzed. Inspections of nearby station equipment are planned to supplement classroom work.

4444. HIGH VOLTAGE PHENOMENA

Credit 3 hrs. Spring. Prerequisite, 4302. The study of problems of the normal operation of power systems at very high voltages, of the abnormal conditions imposed by lightning, of the methods employed to assure proper operation of power systems and apparatus under high-voltage conditions, and of the devices available for laboratory testing of equipment under actual or simulated conditions. An invitation to visit electrical manufacturing test facilities is usually accepted. Considerable attention is given to dielectric behavior and testing techniques.

4543. UNIFIED THEORY OF ELECTROMECHANICAL SYSTEMS

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisites, 4441, 4442, or consent of instructor. Electric machines studied as networks of coupled circuits with periodically varying parameters; forces and torques in electromechanical systems; electromagnetic and electrostatic transducers; Kron's basic machine with its practical derivatives: the synchronous, induction and commutator machines in the transient and steady state; frequency response methods applied to machines.

4545. ELEMENTS OF POWER-SYSTEM ANALYSIS

Credit 3 hrs. Fall. 2 Lect.-Rec., 1 Lab.-Comp. Prerequisite 4302. Studies of power systems through the application of equivalent circuits of synchronous machines, transmission lines, transformers and static loads; power-system network theory; power angle equations and circle diagrams; the two-machine system; load flow and voltage regulation of complex systems; symmetrical components; fault analysis of complex systems; introduction to system stability; use of matrices and the digital computer as computing aids.

4546. TRANSIENT ANALYSIS OF POWER SYSTEMS

Credit 3 hrs. Spring. 2 Lect.-Rec., 1 Lab.-Comp. Prerequisites, 4543, 4545, or equivalent. Study of synchronizing and damping torques for salient-pole and solid-rotor machines; application of constant-flux linkage theorem to balanced and unbalanced faults; basic assumptions for transient stability studies; voltage regulators and governors; control of system frequency; application of a-c network analyzer and digital computers to transient problems; theory of the electric arc; a-c arc interrupting media; simulated testing of circuit breakers.

MICROWAVE AND PHYSICAL ELECTRONICS

4452. PHYSICAL ELECTRONICS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4312. Fundamental theory of electron devices; particle dynamics; generation and formation of electron beams; electrostatic and magnetic lenses; space charge phenomena; limitations at high frequencies; noise; interaction of electron streams and electromagnetic waves in localized and distributed regions; the electron ballistic and space charge wave approaches; application to planar vacuum tubes and microwave tubes.

4553. MICROWAVE ELECTRONICS LABORATORY

Credit 1–3 hrs. 2 Labs. for 3 hrs. credit. Fall. Prerequisites, 4461, 4452. Selected experiments in the area of measurement of active and passive microwave devices including klystrons, traveling-wave tubes, magnetrons, cavities, and periodic structures; term experiment; stress laid upon independent work by the student.

4554. VACUUM AND PHYSICAL ELECTRONICS LABORATORY

Credit 1–3 hrs. 2 Labs. per week for 3 hour credit. Spring. Prerequisites, 4312, 4422. Experiments in the fields of vacuum, gaseous, and solid state electronics; selected experiments involving high-vacuum measurements, r-f mass spectroscopy, gas plasma measurements, evaporation measurements; also selected experiments involving such techniques as film evaporation, ceramic-metal sealing; production of ultra-high vacuum; term experiment.

4651. ADVANCED PHYSICAL ELECTRONICS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4512. A study of the physical theories underlying devices based on the controlled flow of electric charges in vacuum, gases, and solids. Review of the fundamental principles: energy exchange, effects of magnetic fields, space charge, collisions, velocity spread, etc. Charge flow across metal-vacuum boundaries: thermionic, secondary, photoelectric, and high field emission. Charge flow across semiconductor contacts: diodes, transistors, field effect transistors. Tunneling phenomena: thin films, tunnel diode analysis. Thermionic devices: high power electron optics, classical electron devices. Gaseous electron devices.

4652. MICROWAVE ELECTRONICS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4512. Fundamental theories of high vacuum, gaseous, and solid state microwave devices. Review of fundamental relations: wave equation, equations of motion, power flow, Liouville equation, etc. Field theory for electron and gaseous electron devices: study of kylstrons, traveling wave tubes, wave propagation in stationary plasmas, Faraday effect, etc. Coupled mode theories and ballistic theories. Generalized study of electron stream networks with application to microwave tubes and to solid state microwave dielectric diodes and triodes. Properties of solid state devices at microwave frequency: microwave transistors, parametric diodes, tunnel diodes, injection lasers, gas lasers. Discussion of contemporary topics: Gunn oscillator, approaches to high power solid state microwave generation, etc.

4653. ADVANCED MICROWAVE THEORY I

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4512. Intended primarily for graduate students. Microwave circuit theory with emphasis on mathematical techniques. Use of perturbational and variational techniques. Green's functions and scattering matrices for solution of microwave circuit problems. Normal modes in uniform waveguides and cavities; excitation of waveguides; obstacles in waveguides and microwave junctions; quasi-stationary approximations; equivalent circuits.

4654. ADVANCED MICROWAVE THEORY II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4653. Intended primarily for graduate students. Microwave circuit theory with emphasis on mathematical techniques. Inhomogeneous media; ferrites and nonreciprocal networks; microwave filters; periodic circuits; surface waveguide; radiation systems.

WAVE PROPAGATION AND PLASMA PHYSICS

4461. ELECTROMAGNETIC THEORY

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4311. Foundation of electromagnetic theory; vector analysis and introductory potential theory; electrostatic fields in vacuum and dielectrics; magnetic fields and magnetic materials; Maxwell's equations; electromagnetic waves in space, waveguides and cavities; excitation of waveguides; boundary value problems; radiation and scattering of waves. Emphasis will be on mathematical technique.

4462. WAVE PROPAGATION IN THE ATMOSPHERE I

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 4311, 4312. An elementary treatment of wave phenomena in the lower and upper atmosphere of the earth, including radio waves, plasma waves, acoustic waves, and gravity waves.

4467. RADIO ENGINEERING

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisites, 4311, 4302. A study of communication circuits with distributed constants and the production and propagation of electromagnetic radiation; transmission line theory and applications; impedance matching; ultra-high-frequency generation and transmission; electromagnetic theory; propagation phenomena; antenna characteristics and radiation.

4560. RADIO AND COMMUNICATION LABORATORY

Credit 3 hrs. Spring normally, but either term if demand is sufficient. 1 Rec., 1 Lab. Prerequisites, 4467, 4422. Choice of three to five different experiments from the field of electronic circuits, networks, transmission lines; waveguides and antennas, Experiments selected to meet individual needs.

4561. PLASMA PHYSICS I

Credit 3 hrs. Fall. 3 Lect. Prerequisites, 4311, 4312. Available to fourth year students with permission of instructor. Motion of charged particles in fields; adiabatic invariants; collisions; coulomb scattering and bremsstrahlung; Langevin equation; transport coefficients; ambipolar diffusion; elementary discharge theory; plasma oscillations and waves: hydromagnetic equations; diffusion of magnetic lines; plasma confinement and mascroscopic instabilities; test particle in a plasma.

4562. PLASMA PHYSICS II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4561 or permission of instructor. MHD equations; low-conductivity channel flow; Alfven waves; Friedrich's diagrams; shock waves; magneto-active cold plasma theory; CMA diagrams; quasi-longitudinal and quasi-transverse approximation; whistlers and radio waves; bounded plasma: cyclotron radiation; applications to laboratory and natural phenomena.

4566. WAVE PROPAGATION IN THE ATMOSPHERE II

Credit 3 hrs. Spring. Prerequisites, 4462 or equivalent, and 4565 or equivalent. Advanced treatment of special topics in radio wave propagation in the atmosphere. Propagation: Whistler mode; earth-ionosphere waveguide mode;

ducting phenomena. Scattering: weak scattering by turbulent irregularities of refractive index in the lower atmosphere; back scattering by thermal fluctuations of electron density in the ionosphere.

4567. ANTENNAS AND RADIATION I

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4311. Linear radiators: formulation of the electromagnetic field in terms of vector and scalar potentials; radiation from an infinitesimal current element; radiation from short dipoles; small loops; resonant wire antennas; long wire antennas; theory of linear arrays; impedance properties of wire antennas; antennas with parasitic elements. Aperture radiators: uniqueness theorem for vector fields; equivalence and induction principle; radiation from open-ended waveguides; horn antennas; reflector antennas; Babinets principle; slot antennas.

4568. ANTENNAS AND RADIATION II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4567 or equivalent. Huygens' Principle for electromagnetic fields; application to problems of diffraction and aperture radiators; surface wave antennas; radiation in media other than free space; antenna thermodynamics.

4661. KINETIC EQUATIONS

Credit 3 hrs. Fall. 3 Lect. Prerequisites, 4561, 4562, or permission of instructor. Critical development of the Liouville equation; concept of the ensemble and N-particle distribution function; formulation of the Boltzmann, Vlasov, Fokker-Planck and B-G-K equation from the BBKGY scheme; the correlation function; approach to equilibrium; coarse graining; ergodic and H-theorems; equilibrium ensembles; the transition from microscopic to macroscopic descriptions; two particle and radial distributions; Percus-Yevic theory; Density Matrix.

4662. KINETIC THEORY OF PLASMA

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 4561, 4562, or permission of instructor. Boltzmann equation; Lorentz model, transport coefficients for weakly ionized gases; moments of Boltzmann's equation; MHD equations, Chew-Goldberger-Low theory; relativistic and quantum mechanical modifications of Vlatsov equation; waves in hot plasmas; Landau damping, velocity-space instabilities, quasi-linear theory, fluctuations, cyclotron and Cerenkov radiation from plasma; coulomb scattering and Fokker-Planck equation.

SYSTEMS

4403. SYSTEMS ANALYSIS

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisites, 4302, and Mathematics 422. (Intended for honors students) Application of mathematical concepts to the analysis of linear systems subjected to arbitrary excitations. Analysis of systems containing passive elements and controlled sources; flow graphs, feedback and stability, methods for determining system stability, signal generation, and analysis of linear and nonlinear oscillators. Physical realizability, linear time varying networks. Applications of the formal analysis techniques to systems of practical importance will be presented in the recitation-computing sections.

4404. PROBABILITY THEORY AND SYSTEM APPLICATIONS

Credit 4 hrs. Spring. 4 Lect. Prerequisite, 4403. (Intended for honors students) Mathematical development of probability theory with applications to random processes in linear systems. Basic rules of probability; sets; combinational analysis. Random variables; expected values; characteristic functions. Statistical averages; law of large numbers. Random processees; correlation functions; power spectral densities. Linear system analysis with random input; input-output relations. Gaussian processes in linear systems. Selected topics in the statistical aspects of system analysis. Individual preparation and seminar presentation of selected topics will be encouraged.

4503. THEORY OF LINEAR PHYSICAL SYSTEMS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4402 or 4404, or consent of instructor. The state space approach to linear system theory. The concept of state; basic properties of the state and the state equation; state vectors and equations of linear differential systems; modes in linear systems; time varying linear systems; the adjoint system; stability; generalized functions and the Fourier Transform; properties of system functions; discrete-time linear systems; controllability, and observability.

4504. THEORY OF NONLINEAR SYSTEMS I

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4503. Analysis of first and second order nonlinear systems with applications. Phase plane analysis of autonomous systems; singular points, limit cycles, and the theory of equilibrium; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; perturbation theory, existence, convergence, and periodicity of perturbation series; method of Krylov and Bogoliubov. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic sysems, Floquet theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically-excited systems.

4571. NETWORK THEORY

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4402 or equivalent. Concept of activity and passivity. Application of linear graph theory to the analysis of electrical networks. Multi-pole analysis of active and passive networks. Physical realizability conditions of one-port, two-port passive reciprocal, non-reciprocal, and active networks. Positive real functions. Interrelationship of parts of network functions. The approximation problem in the frequency and the time domain.

4572. NETWORK SYNTHESIS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4571. Active and passive elements and devices. Driving-point and transfer function realization techniques of LC, RC (RL), RLC, and various active networks. Sensitivity considerations. Practical realizations. Predistortion. Equivalent networks.

4573. RANDOM PROCESSES IN ELECTRICAL SYSTEMS I

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4402 and consent of instructor, or 4404. Inadequacy of a deterministic formulation of communication and control problems. Combinatorics and discrete probability. Elements of set theory, and non-denumerable sample spaces. Random variables and their transformations. Moments and correlations. The properties of the normal distribution. The weak and strong laws of large numbers. Engineering importance of exponential convergence. The characteristic functions and the central limit theorem. Problems illustrating use of the developed theory in systems analysis and design.

4574. RANDOM PROCESSES IN ELECTRICAL SYSTEMS II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4573. Dependence of random variables: Markov chains. Generalization of random sequences to processes. The linear theory of stationary random processes. Relation of time to statistical averages. Spectral analysis and eigenfunction expansions. Applications of above theory to linear filtering. Non-stationary random processes; input-output relations for nonlinear systems. Markov, Poisson, and Wiener Processes. Formulation of random problems in communication and control.

4581. FEEDBACK CONTROL SYSTEMS

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, 4402 or equivalent. Principles of feedback control systems with emphasis on methods of analysis and synthesis to meet prescribed performance criteria. Electronic, electromechanical, and electrohydraulic components; stability criteria; root locus, Nyquist, and Bode techniques; cascade and feedback compensation of control systems; complex control systems; sampled data feedback control systems. Laboratory exercises in components, transient and frequency response measurements on complete systems, and compensating techniques are integrated with the lecture material.

4582. ADVANCED CONTROL SYSTEMS

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, 4581 or equivalent. Analytical and numerical methods for the investigation and solution of Nonlinear Control Systems; derivation of z-forms; the phase plane; common physical nonlinearities; describing function techniques; stability analysis; relay, or on-off control systems; optimization of relay control systems; dual mode systems; nonlinear compensation techniques; self adaptive control systems. On-off control systems, nonlinear compensation techniques, system design using analog simulation, and system optimization are topics for laboratory study.

4583. ANALOG COMPUTATION

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisites, 4302 and concurrent registration in 4401, or consent of instructor. Concepts and principles of analog computation; scaling and programming linear, non-linear, and time-varying differential equations; direct simulation of electrical and mechanical systems; analog programming using digital logic. Laboratory work involves solution of problems on a general-purpose analog computer and by arrangement can be devoted in part to special projects to suit the interests and needs of the student.

4584. OPTIMIZATION TECHNIQUES IN CONTROL SYSTEMS

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 4503 and 4581, or equivalent in feedback theory. Formulation of parameter, trajectory, and feedback control optimization problems; equality and inequality constraints, penalty functions. Introduction to the calculus of variations, dynamic programming, and Pontriagin's maximum principle; necessary conditions for optimality, boundary conditions, saturation constraints. Iterative methods for solving two-point boundary-value problems by successive approximations; convergence, convexity constraints. Synthesis and structuring of optimal feedback controllers; complexity and stability constraints. Selected topics; sequential optimization, plant optimization, stochastic optimal control, optimal control of distributed parameter plants.

4587. SWITCHING SYSTEMS I

Credit 3 hrs. Fall. 2 Lect. 1 Lab. Prerequisite, 4322. Switching algebra; switching devices; logical formulation and realization of combinational switching circuits; minimization aids; number representation and codes; simple memory devices; synchronous sequential circuits; counters; shift registers and arithmetic units in a digital computer.

4588. SWITCHING SYSTEMS II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4587 or equivalent. Synchronous and asynchronous sequential circuits, formulation and optimization; large-scale memory units, selection and control; further discussion of arithmetic units; integrated study of switching systems including general-purpose digital computer, control switching, and communication switching; introduction to the general theory of learning machines.

4670. ADVANCED TOPICS IN SYSTEM THEORY

Credit 3 hrs. Term dependent upon demand. A course centered about some broad but particular problems of current interest. Topics vary from semester to semester. One of the major aims of the course is to develop the ability of the student to select needed information from available sources.

4671. THEORY OF NONLINEAR SYSTEMS II

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4504. Non-autonomous and higher order nonlinear systems with applications; representation of systems with several degrees of freedom; approximations; use of Liapunov functions in system stability determination and design; describing functions and Aizerman's hypothesis, theory of Lur'e-Letov for nonlinear control; asymptotic expansions for the period behavior of systems under the influence of periodic external forces; method of averaging; systems with slowly varying parameters, Manley-Rowe relations; orthogonal representation of nonlinear systems; nonlinear filters and compensating systems, system optimization.

4673. RANDOM PROCESSES IN COMMUNICATION SYSTEMS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4574. The generation and processing of signals in communication systems. Characterization of time-varying deterministic systems, generalized modulation. Characterization of time-varying non-deterministic systems; random channels, multipath distortion, Doppler shift, signal detection and processing; linear and nonlinear smoothing and prediction, signal-to-noise ratios in simple detectors, matched filters, radar detection and ambiguity functions. Comparison of communication systems in the presence of noise.

4674. TRANSMISSION OF INFORMATION

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4673 or consent of instructor. Selection of fidelity criteria for accurate and efficient transmission of information. Efficient representation of outputs of message sources. The entropy measure and its properties. Encoding for reliable communication through discrete memoryless noisy channels. Rate of information transmission and the probability of decoding error, channel capacity. Systematic codes and the instrumentation problem. Time-discrete continuous channels. Coding and decoding for the band-limited Gaussian channel. Application of information theory to the analysis and design of communication systems.

4680. ADVANCED EXPERIMENTAL CONTROL SYSTEMS

Credit 4 hrs. Either term. 2 Lab. Prerequisite, 4582 or consent of instructor. Limited to graduate students except by special permission. Programs on selected topics in experimental concepts, techniques, and design. Many different experiments are available including: components and systems in the Control System Laboratory; linear and nonlinear system simulation (including compensation) with the analog computer in Phillips Hall and/or the digital computer in the Cornell Computing Center; system optimization (experiment design); discrete control systems; and investigation of methods of adaptation in control systems. During a term the student is expected to perform three to six experiments, selected to meet his individual needs. Emphasis is placed on independent work.

4681. RANDOM PROCESSES IN CONTROL SYSTEMS

Credit 3 hrs. Fall. 3 Lect. Prerequisites, 4574 and 4584. Prediction and filtering in linear control systems; Gaussian-Markov sequence, Gaussian-Markov process, prediction problem, Hamiltonian formulation of filtering problem, generalized Wiener filtering, stochastic optimal and adaptive control problems. Selected topics: Bayes decision rule, min-max policy, maximum likelihood estimate, control of systems with uncertain statistical parameters; stochastic differential equations, optimal nonlinear filtering; Gaussian input describing function, stability of control systems with random parameters.

4682. SEMINAR IN CONTROL SYSTEMS

Credit 2 hrs. Fall or Spring. Prerequisites, 4582, 4681. Open to graduate students who are doing research in the area of control system engineering. Presentation and discussion of current research and publications in control systems and switching systems.

GENERAL

4491. ILLUMINATING ENGINEERING

Credit 3 hrs. Fall 3 Rec. Prerequisite, Physics 224. Basic concepts, units and relations in current illuminating engineering. Light sources and computation of light distribution followed by seminar pursuit of current literature on researches and application. Emphasis will be given human reactions to light including color vision, visual comfort, and perception of visual tasks.

4492. ILLUMINATING ENGINEERING

Credit 3 hrs. Spring. 2 Rec., 1 Lab.-Comp. Prerequisite, 4491. Computation of light-flux distribution and study of difficult lighting problems; emphasis on specialized rather than general lighting problems.

4590. SPECIAL TOPICS IN ELECTRICAL ENGINEERING

Credit 1 to 3 hrs. Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

4591 AND 4592. PROJECT

Credit 3 hrs. Fall and spring. Individual study, analysis, and usually experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing his project; an engineering report on the project is required.

4593. FUNDAMENTALS OF ACOUSTICS

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Laboratory assignments to meet individual needs. Prerequisites, 4401, 4403, or permission of the instructor. Vibrations in strings, bars, membranes, and plates; plane and spherical acoustic waves; transmission, reflection, absorption, resonators and filters; loudspeakers and microphones; speech, hearing, and noise; architectural accoustics; ultrasonic and sonar transducers; underwater acoustics.

COURSES FOR OTHER ENGINEERING CURRICULA

4950. ELECTRICAL ENGINEERING

Credit 4 hrs. Spring. 3 Lect., 1 Comp. Prerequisite, 241. Introductory concepts; nonmetallic conduction; electric circuit laws and D-C circuits; magnetics; electromagnetic induction; energy storage elements; alternating currents; analysis of sinusoidally excited circuits; transformers; amplifying devices; linear analysis of electronic circuits; electronic instrumentation; feedback and control; control of discontinuous current flow; D-C machines; A-C machines.

CHEMICAL ENGINEERING

5041. NONRESIDENT LECTURES

Fall. 1 Lect. Given by lecturers invited from industry and from certain selected departments of the University for the purpose of assisting upperclass students in their transition from college to industrial life.

5101. MASS AND ENERGY BALANCES

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Parallel, Physical Chemistry 285. Engineering problems involving material and heat balances. Flow-sheet systems and balances. Total energy balances for flow systems. Messrs. Winding and Wingard.

5102. EQUILIBRIA AND STAGED OPERATIONS

Credit 3 hrs. Spring. 2 Lect., 1 Comp. Parallel, Physical Chemistry 286. Phase equilibria and phase diagrams. The equilibrium stage; mathematical description of single and multistage operations; analytical and graphical solutions. Messrs. Winding and Wingard.

5103, 5104. CHEMICAL ENGINEERING THERMODYNAMICS

Credit 3 hrs. each term. Fall-spring. 3 Lect. Prerequisites, Chemistry 285, 286. A study of the first and second laws with application to batch and flow processes. Physical and thermodynamic properties. Availability; free energy; chemical equilibrium. Application to gas compression; process steam; power generation; adiabatic reactors; and chemical process development. Mr. Von Berg.

5105. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5104 or equivalent. Primarily for graduate students. Application of the general Thermodynamics method to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties. Chemical and phase equilibria. Mr. Leinroth.

5106. REACTION KINETICS AND REACTOR DESIGN

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5104. A study of chemical reaction kinetics and principles of reactor design for chemical processes. Mr. Von Berg.

5107. ADVANCED REACTION KINETICS

Credit 3 hrs. Fall. 3 Lect. Primarily for graduate students. Effects of heat transfer, diffusion, and non-ideal flow on reactor performance. Optium design for complex reactions. Analysis of current literature on topics such as partial oxidation, catalytic cracking, hydrogenation, and polymerization. Mr. Harriott.

5108. COLLOIDAL AND SURFACE PHENOMENA

Credit 3 hrs. Fall. Prerequisite, physical chemistry. Lectures, demonstrations, and problems in the physics and chemistry of small particles and surface films. Topics include surface energy, surface films, electrokinetics, and colloidal behavior. Applications to detergency, emulsion, catalysis, lubrication, and behavior of natural products. Mr. Finn.

[5161. PHASE EQUILIBRIA

Credit 3 hrs. Fall. 3 Lect. Prerequisite, physical chemistry. A discussion of the phase rule and interpretation of phase diagrams. A detailed study of the pressure-temperature-composition-relations in binary and multicomponent heterogeneous systems where several phases are of variable composition. Aqueous salt systems and metal systems will also be considered. Prediction of phase data. Mr. Thorpe. Not offered in 1965–66.]

5203, 5204. CHEMICAL PROCESSES

Credit 2 hrs. 2 Lect. Prerequisite, physical chemistry. An analysis of important chemical processes and industries. Fall term, inorganic chemical processes; spring term, organic chemical processes. Mr. Wiegandt.

5205. CHEMICAL PROCESS SEMINAR

Credit 2 hrs. Fall. For graduate students. A discussion of recent advances in chemical processes. Mr. Wiegandt.

5255, 5256. MATERIALS OF CONSTRUCTION

Credit 3 hrs. each term. 3 Lect. Prerequisites, 5101, 5102, Chem. 285, 286. An introductory presentation of the nature, properties, treatment, and applications of the more important metals and alloys, including extractive and physical metallurgy and behavior under service conditions. Non-metallic materials, including refractories, cement, protective coatings, and plastics, are also discussed. Messrs. Mason, Cocks, and Rodriguez.

5303. ANALYSIS OF STAGE PROCESSES

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisites, 5101 and 5102. An analysis of separations involving mass transfer in stage processes. Design variables, binary and multicomponent system calculations, efficiencies, and cost estimation for stage processes are considered. Mr. Leinroth.

5304. INTRODUCTION TO RATE PROCESSES

Credit 3 hrs. Spring. 2 Lect., 1 Comp. Prerequisite, 5303. An introduction to fluid mechanics and heat transfer. Mr. Smith.

5305. RATE PROCESSES AND UNIT OPERATIONS

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisite, 5304. Rate of mass transfer; analysis of chemical engineering systems. Extension of previous studies to cover the interrelation and transient aspects of unit operations. Mr. Smith.

5353. UNIT OPERATIONS LABORATORY

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, 5304. Laboratory experiments in fluid dynamics, heat transfer, and mass transfer. Correlation and interpretation of data. Technical report writing. Messrs. Harriott and Finn.

5354. PROJECT LABORATORY

Credit 3 hrs. Spring. Prerequisite, 5353. Special laboratory projects involving bench-scale or pilot-plant equipment. Messrs. Harriott and Leinroth.

5505. ADVANCED HEAT TRANSFER

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5507 or equivalent. Advanced topics in heat transfer. Heat transfer under unsteady-state conditions; numerical approximation methods; analogies among heat, mass, and momentum transfer; heat transfer to liquid metals; simultaneous heat and mass transfer, etc. Primarily for graduate students. Mr. Smith.

[5506. DIFFUSIONAL OPERATIONS

Credit 3 hrs. Spring. 3 Lect. Primarily for graduate students. Advanced topics in diffusional operations. Molecular and turbulent diffusion in binary and multicomponent systems; film, boundary layers, and penetration-theory models of mass transfer; applications to distillation, gas absorption, liquid-liquid extraction, and other industrial operations. Mr. Scheele. Not offered in 1965–66.]

5507. ADVANCED FLUID DYNAMICS

Credit 3 hrs. Fall. 3 Lect. Primarily for graduate students. Advanced topics in fluid dynamics. Viscous laminar flow of Newtonian and non-Newtonian fluids; flow stability; turbulent flow; perfect fluid theory; boundary layer theory; analogies among heat, mass, and momentum transfer.

[5508. APPLIED MATHEMATICS IN CHEMICAL ENGINEERING

Credit 4 hrs. Fall. 4 Lect. Prerequisite, 5305, 5104. Series and numerical solutions. Partial differential equations. Fourier Series; Bessel Functions; Laplace transforms. Calculus of finite differences. Applications to heat and mass transfer, reaction kinetics, and catalysis. Not offered in 1965–66.]

5605, 5606, 5607, 5608. DESIGN PROJECT

Credit variable. Fall and spring. Individual projects involving the design of chemical processes and plants. Estimation of costs of construction and operation, variation of costs and profits with rate of production, etc. Staff.

5609. ANALYSIS AND DESIGN OF PROCESS EQUIPMENT

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5304 or consent of instructor. Discussion and analysis of operating principles, design, and selection of chemical process equipment. Primary emphasis is on operations involving solids and fluid-solid mixtures such as mixing, mechanical separations, size reduction, crystallization and drying. Mr. Smith.

5621. PROCESS DESIGN AND ECONOMICS

Credit 6 hrs. Fall. Prerequisites, 5104, 5204, 5304. Methods for estimating capital and operating costs. Performances, selection, design, and cost of process equipment. Process development and design. Market research and survey. Oral and written presentation. Mr. York.

5622. PROCESS AND PLANT DESIGN

Credit 6 hrs. Spring. Prerequisite, 5621. Continuation of 5621. Process design, including reactors, process equipment, and separating systems. Layout and model of process units. Plant location, design, and layout. Cost estimates and project evaluation; equivalent interest rate of return and discounted cash flow. Oral and written presentation. Mr. York.

[5631. SEPARATION PROCESSES

Credit 3 hrs. Fall. Prerequisite, 5305. Problems involving the optium design of equipment for the physical separation of chemical mixtures. Primarily for graduate students. Not offered in 1965–66.]

[5632. PROCESS EVALUATION AND DESIGN

Credit 4 hrs. Spring. Prerequisite, 5631. Techniques and case studies in evaluating chemical processes. Cost estimation for processes, equipment, and plant. Not offered in 1965–66.]

5635. MARKETING OF CHEMICAL PRODUCTS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5621. Examination of marketing activities, organizations, and costs in the distribution of chemicals. Technical and economic problems related to selling and shipping. Chemical prices. A market research project is required. Mr. Hedrick.

5636. ECONOMICS OF THE CHEMICAL ENTERPRISE

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5622. Research economics; feasibility studies; information services; venture analysis; depreciation and amortization; planning. Mr. Hedrick.

5641. INVENTIONS, PATENTS, AND TRADE SECRETS

Credit 3 hrs. Fall. Prerequisite, or parallel, 5621. Protection of inventions and trade secrets. Statutory and other legal requirements for patentability of inventions. Effect of contributory infringement on product development and marketing. Evaluation of patents. Role and management of patents in planning growth and expansion into new product lines. Mr. York.

5642. DEVELOPMENT ECONOMICS

Credit 3 hrs. Spring. Prerequisites, 5621, 5622, and 5641. Planning, evaluation, and management of development activities in the process industries, as related to research, processing, new products, markets, and long-range growth. Quantitative treatment, wherever practical. Mr. York.

5717. PROCESS CONTROL

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, 5304. Dynamic response of processes and control instruments. Use of frequency response analysis, Laplace transforms, and electronic analogs to predict the behavior of feedback control systems. Mr. Harriott.

5741. PETROLEUM REFINING

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5304. A critical analysis of the processes employed in petroleum refining. Mr. Wiegandt.

5742. POLYMERIC MATERIALS

Credit 3 hrs. Fall. 3 Lect. Polymerization reactions, manufacture and properties of synthetic resins, fibers, plastics, and rubbers. Mr. Rodriguez.

5743. PROPERTIES OF POLYMERIC MATERIALS

Credit 3 hrs. Spring. Prerequisite, 5742. Mechanical, electrical, and optical properties of polymers. Phenomenological aspects and molecular theories of non-Newtonian flow viscoelasticity and ultimate tensile properties. Mr. Rodriguez.

5745. ANALYSIS OF POLYMERIC PROCESSES

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5742. Technical and economic evaluations of the principal processes used in manufacture of resins, plastics, and elastomers, including analyses of raw materials, reactor systems, product preparation, and problems in distribution and marketing. Special emphasis on new processes and means of reducing capital and operating costs. Mr. Hedrick.

5746. CASE STUDIES IN THE COMMERCIAL DEVELOPMENT OF CHEMICAL PRODUCTS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, or parallel, 5622. For graduate and selected fifth year students. Detailed analysis of specific cases involving the development of new chemical products. Particular emphasis is given to planning activities, research justification, and market forecasting. Profitability calculations and projections are required. Mr. Hedrick.

5748. FERMENTATION ENGINEERING

Credit 3 hrs. Spring. 2 Lect., 1 Rec. Prerequisites, or parallel courses, Chemistry 286, and any course in microbiology. An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation. Mr. Finn.

5749. INDUSTRIAL MICROORGANISMS

Credit 1 hr. Fall. 1 Lect. Prerequisites, organic chemistry and physical chemistry. A brief introductory course in microbiology for students with a good background in chemistry. Mr. Finn.

5752. POLYMERIC MATERIALS LABORATORY

Credit 2 hrs. Fall. 1 Lab. Prerequisite, 5742. Experiments in the formation, characterization, fabrication, and testing of polymers. Mr. Rodriguez.

5760. NUCLEAR AND REACTOR ENGINEERING

Credit 2 hrs. Spring. 2 Lect. Prerequisite, 8302 or consent of the instructor. Fuel processing and isotope separation, radioactive waste disposal, fuel cycles, radiation damage, biological effects and hazards, shielding, power reactors. Mr. Von Berg.

5851. CHEMICAL MICROSCOPY

Credit 3 hrs. Either term. 1 Lect., 2 Lab. Prerequisites, or parallel courses, Chemistry 285, 286, or 387, 388 and Physics 223, 224 or special permission. Microscopical examination of chemical and technical materials, processes and products. Measurement, particle size determination, analyses of mixtures, crystallization, phase changes and colloidal phenomena, lens systems and photomicrography. Messrs. Cocks and Mason.

5853. MICROSCOPICAL QUALITATIVE ANALYSIS (INORGANIC)

Offered on demand either term. Credit 2 hrs. or more. Prerequisite, 5851. Laboratory periods to be arranged. Laboratory practice in the analysis of inorganic substances containing the more common elements. Mr. Mason.

5859. ADVANCED CHEMICAL MICROSCOPY

Offered on demand either term. Credit 1 hr. or more. Prerequisite, 5851 and special permission. Laboratory practice in special methods and special applications of chemical microscopy. Mr. Mason.

5900. SEMINAR

Credit 1 hr. Fall-spring. General chemical engineering seminar required of all graduate students majoring in the field of chemical engineering.

5909. RESEARCH SEMINAR

Spring. 1 Lect. Required of all students enrolled in the predoctoral honors program. An introduction to the research methods and techniques of chemical engineering. Mr. Winding.

5952, 5953, 5954. RESEARCH PROJECT

Credit 3 hrs.; additional credit by special permission. Fall-spring. Prerequisite, 5304. Research on an original problem in chemical engineering. Staff.

5955, 5956. SPECIAL PROJECTS IN CHEMICAL ENGINEERING

Credit variable. Either term. Research or studies on special problems in chemical engineering. Staff.

MATERIALS SCIENCE AND ENGINEERING

6301. STRUCTURE OF MATERIALS I

Credit 3 hrs. Fall. 3 Lect.-Rec., 1 Lab. Characterization of metallic and nonmetallic structures by standard metallographic techniques, principally optical microscopy and X-ray diffraction. Structures and properties of materials are related to composition and thermal history. Techniques of specimen preparation, principles and use of light microscopes and metallographs are treated. X-ray diffraction theory and techniques are introduced and applied to metallographic problems. Mr. Newkirk.

6302. STRUCTURE OF MATERIALS II

Credit 3 hrs. Spring. 1 Lect., 2 Labs. Prerequisite, 6301. A continuation of 6301 with emphasis on laboratory work and on the subject of structural changes in specific materials resulting from particular mechanical and thermal treatments. Quantitative microscopy is included as well as more advanced techniques in X-ray diffraction, such as pole figure determination by diffractometer method and chemical analysis by X-ray fluorescence. Mr. Newkirk.

6311. MATERIALS SCIENCE I

Credit 4 hrs. Fall. Prerequisites, Chemistry 276 or 285, Applied Differential Equations 1155, Physics 224, 226 or 228, Mechanics 211. 3 Lect. One 2½ hr. lab. per week as assigned. Binding of atoms. Arrangement of atoms in molecules and crystals. Diffraction and structure. Equilibrium of assemblies of matter. Rate processes involving assemblies of matter. Metastable states of matter. Elastic and plastic deformation of matter under static and dynamic stress. The laboratory work includes experiments in crystal structure by X-ray diffraction, phase equilibria using thermal analysis and quenching, microstructure of materials using microscopy, crystalline imperfections by quenching and electrical resistivity and by polarized light and etch pits, diffusion of carbon in iron by carburizing and hardness profiles and by internal friction, metastable states studied by microstructure and hardness, mechanical properties of materials by tensile testing. Messrs. Ruoff, Taylor, and Staff.

6312. MATERIALS SCIENCE II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 6311. An introduction to electrical and magnetic properties of materials with emphasis on structural aspects. Classification of solids; charge and heat transport in metals and alloys; semiconductors and insulators; principles of operation and fabrication of semiconductor devices; behavior of dielectric and magnetic materials; phenomenological description of superconducting materials.

6316. MATERIALS ENGINEERING

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Selection and processing of materials for engineering applications. The effect of processing on the structure and properties of the materials and the control of properties by variations in processing is emphasized. Processing methods considered involve solidification, plastic deformation, heat treatment, material bonding, and consolidation of powders. Mr. Jeffrey.

6321. MATERIALS SCIENCE

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite physical chemistry. An abbreviation of 6311. Messrs. Ruoff, Taylor, and staff.

6423. THERMODYNAMICS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 8121 or equivalent. Application of thermodynamics, topics include solutions, phase equilibria, defects in solids, surfaces and order-disorder reactions. Mr. Blakely.

6432. MECHANICAL METALLURGY

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 6301, 6311, and 6313. Elastic, plastic, and fracture phenomena in metallic solids, including yielding, strain hardening, brittle fracture, creep, and fatigue. Mr. Smith.

6435. PHYSICAL METALLURGY

Credit 4 hrs. Fall. Lects. Prerequisites, 6302, 6311, Physics 314 or 436. Structural basis of the physical behavior of materials with emphasis on metals. Consideration of atomic basis of phase stability and resulting physical properties. The kinetics and mechanisms of phase transformations involving condensed systems; nucleation, crystal growth and solidification, diffusion, precipitation, oxidation, polyphase transformations, diffusionless transformations. Mr. Balluffi.

6442. MATERIALS PROCESSING I (Chemical)

Credit 4 hrs. Spring. 3 Lect. 1 Lab. Recovery and refining of metals. Production of ferrous and non-ferrous alloys. Manufacture and utilization of refractories. Mr. Gregg.

6443. MATERIALS PROCESSING II (Mechanical)

Credit 4 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, 311. A course relating basic and applied sciences to the processing of metallic and non-metallic materials and developing a critical analysis of processing methods. The effect of processing on the properties of the materials, and control of material properties by variations in processing is emphasized. Also considered are the effects of environmental conditions and the kinetics of the processes. Lecture material emphasizes the theoretical principles involved in processing, while the laboratory, which is integrated with the lectures, includes experiments involving both principles and actual processing procedures. Processing methods considered include solidification, deformation, heat treatment, material bonding, material removal, consolidation of powders and others. Mr. Burton.

6503. SERVICE BEHAVIOR OF METALS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 6432 Metallurgical and mechanical factors governing the selection of metals for various services. Analysis of service requirements, and the selection and fabrication of metals to fulfill such requirements; analysis of service failures of metals and remedies for such failures; and study of the merits and limitations of materials applications in existing products and equipment. Mr. Smith.

6506. METALLURGICAL DESIGN

Credit 2 hrs. Spring. Prerequisite, 6432 or 6503. A seminar course using a modified case-history approach to problems and current developments in metallurgical engineering. Mr. Smith.

6524. KINETICS OF REACTIONS IN SOLIDS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 6423 or equivalent. Designed for advanced undergraduates; considers rate theory, transport process, irreversible thermodynamics and their applications. Mr. Li.

6539. PRINCIPLES OF METALLURGICAL ENGINEERING

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 6442 or consent of instructor. Discussion and calculations concerning fuels, fluid flow, heat flow, roasting and sintering, gas cleaning, and application of thermochemical data to metallurgical processes. Mr. Gregg.

6551. PRODUCTION OF METALS AND CERAMICS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 6442 or consent of instructor. Discussions and calculations concerning fuels, fluid flow, heat flow, roasting and sintering, gas cleaning, and application of thermochemical data to metallurgical processes. Production and utilization of refractories. Mr. Gregg.

6552. MATERIALS ENGINEERING (CASE STUDIES)

Credit 3 hrs. Spring. Engineering problems which involve mechanical, chemical, electrical, thermal, and aerodynamic design specifications are reviewed as examples of materials selection processing, and use. The case study method is used to evaluate designs, investigate service failures, and select suitable materials and processing techniques. Students make engineering analyses and propose materials for specific applications. Mr. Scala.

6553, 6554. PROJECT

Credit 3 hrs. Fall-spring. Research on a specific problem in materials or metallurgical engineering.

6651. PHYSICAL METALLURGY OF FERROUS MATERIALS

Credit 2 hrs. Spring. 2 Lect. Prerequisite, consent of instructor. Study of the basic effects of alloying on the structure and properties of steels, and the application of this knowledge to the design of modern high-strength, stainless, or heat-resistant steels and of steels for tools and dies. Mr. Smith.

6661. METALS AT ELEVATED TEMPERATURES

Credit 2 hrs. Fall. 2 Lect. Prerequisite, consent of the instructor. Evaluation and application of metals for use at service temperatures. Emphasis is placed on nature of creep flow and fracture at elevated temperatures. Attention is also paid to scaling, metallurgical instability, and pertinent physical properties. Mr. Smith.

6662. REFRACTORY MATERIALS

Credit 3 hrs. Spring. 2 Lect., 1 Lab. The lectures review the crystallography, rheology, and engineering characteristics of refractory metals (tungsten, molybdenum, columbium, and tantalum); graphites; refractory oxides (magnesia, alumnia, zirconia, beryllia and thoria); and the refractory compounds (carbides, nitrides, borides, and beryllides). Laboratory demonstrations supplement the lectures, illustrating plasma and high temperature techniques, and electron beam applications. Research laboratories actively involved in studying these materials are visited. Mr. Scala.

6665. MATERIALS FOR SPACECRAFT AND MISSILES

Credit 2 hrs. Fall. 2 Lect. The basic phenomena and interactions occurring in re-entry, space environment, propulsion and conversion for electrical power will be reviewed as they apply to materials behavior and properties. The principal problems involving mechanical, chemical, electrical and/or aerodynamics interactions will be discussed relative to the compromises in translating the system and mission requirements into working solutions though materials. Supersonic powered flight vehicles, ballistic missiles, and space vehicles will be reviewed as engineering applications of materials. Mr. Scala.

6669. INTRODUCTORY PHYSICAL CERAMICS

Credit 2 hrs. Spring. 2 Lect. The properties and behavior of ceramics as single and poly-crystalline non-metallic inorganic materials, and as composites will be reviewed based on crystal structure, atom mobility, and structural imperfections. The surface effects, interfaces, composition, and microstructure of ceramics will be studied as a background for their behaviors during sintering and forming and as thermal, electrical and mechanical properties, with discussions on nucleation, crystal and grain growth and vitrification. Mr. Scala.

6671. PRINCIPLES OF POWDER METALLURGY

Offered on demand. Credit 3 hrs. Spring. Lect. and Lab. Following brief consideration of industrial powder-metallurgy equipment including dies, presses, and sintering furnaces, and industrial applications such as porous products, permanent magnets, refractory metals, cemented carbides, cermets, etc., the theory of powder metallurgy is treated critically. Emphasis is on the theories of compacting and sintering, diffusional processes, and surface chemistry. The theories, applications, and limitations of hot pressing are examined. Laboratory experimentation is primarily concerned with fundamental investigation of compacting, bonding, sintering, hot pressing, infiltration of porous networks, etc. Laboratory studies of surface chemistry and surface activities are included. Mr. Burton.

6872. NUCLEAR MATERIALS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, Materials Science, Physical Chemistry, or equivalent and consent of instructor. At level of courses for the M.Eng. degree, for example, M.Eng. (Nuclear). Application of materials science to choice and design of systems used in nuclear reactors. Emphasizes effects of basic phenomena, conditions or variables encountered in reactors such as irradiation, temperature, temperature differences, composition and structure. Brings in preparation, fabrication and use of reactor materials and components. Mr. Howe.

Graduate Core Program: Materials Science and Engineering

6601. MATERIALS SCIENCE I: THERMODYNAMICS AND KINETICS IN CONDENSED SYSTEMS

Credit 3 hrs. Basic thermodynamic and kinetic concepts with applications to solids and liquids. Discussion of phase equilibria, solutions, defects, interfaces, reaction rate theory, transport processes, diffusion, relaxation phenomena, etc. At the level of books such as Slater, *Introduction to Chemical Physics;* Guggenheim, *Thermodynamics;* and Shewmon, *Diffusion in Solids.*

6602. MATERIALS SCIENCE II: PHASE TRANSFORMATIONS

Credit 3 hrs. Crystal growth theory including surface transport, spiral growth, impurity inhibition, etc.; nucleation theory, homogeneous and heterogeneous nucleation, spinodal decomposition; solidification, constitutional super-cooling, zone refining, eutectic solidification; solid state transformation, eutectoid, pearlite, bainite, martensite, precipitation, Guinier-Preston zones; recrystallization, recovery, grain growth, boundary migration. At the level of review articles in *Progress in Materials Science (Metal Physics)* and the *Solid State Physics* series.

6603. MATERIALS SCIENCE III: CRYSTAL MECHANICS

Credit 3 hrs. Symmetry, physical properties, and wave propagation in crystalline solids are subjects amenable to a unified treatment. Topics include crystallography, point and space groups, stereographic projection; physical properties, cartesian tenses representation of elastic, electric, magnetic, optic, etc., properties of crystals; waves in crystals, diffraction of x-rays, electrons, and neutrons, elastic waves, lattice dynamics. At the level of Nye, *Physical Properties of Crystals*, and Guinier, *X-Ray Diffraction in Crystals, Imperfect Crystals, and Amorphous Bodies.*

6604. MATERIALS SCIENCE IV: DISLOCATIONS AND DEFORMATION

Credit 3 hrs. Dislocation elasticity including dislocation arrays, phase interfaces, and grain boundaries; dislocation reactions, networks, and stacking faults; interactions with line, point, and plane defects; thermal and electrical resistivity; dislocation dynamics, core problem, internal friction; applications to fracture, yielding, strain hardening, fatigue, etc. At the level of Friedel, *Les Dislocations,* and DeWit, *Continuum Theory of Stationary Dislocations, Solid State Physics* Vol. 10.

6605. MATERIALS SCIENCE V: ELECTRONIC PROPERTIES OF ENGINEERING MATERIALS

Credit 3 hrs. Structural chemistry, atomic binding in metals, polymers, and ionic solids; electronic structure of metals, anisotropy, Fermi surfaces, alloy theory, ferromagnetism, domain, defect sensitivity, electronic structures, thin films; superconductivity, phenomenology, defect sensitivity; insulators, optical properties, dielectric constant; semiconductors; ferrites. At the level of Kittel, *Introduction to Solid State Physics* and review articles in the *Solid State Physics* series.

6606. MATERIALS SCIENCE VI: ADVANCED MATERIALS SCIENCE LABORATORY

Credit 3 hrs. per term. A number of experiments are available in the areas of diffusion, electrical and magnetic properties, deformation and fracture, phase transformation, materials processing, point and line defects, surface physics, and optical properties. During the term a student is expected to complete four to six experiments selected to fit his interests. Independent work by the student is considered essential.

AEROSPACE ENGINEERING

7101. ADVANCED KINETIC THEORY

Credit 3 hrs. Fall. The Boltzmann equation. Solution for gas in equilibrium. Collision frequency and mean free path calculations. Conservation equations. Review of Enskog-Chapman theory of transport coefficients. Grad's thirteen moment equations. The BGK equation. The BBGKY theory. Mr. de Boer.

7102. GASDYNAMICS

Credit 3 hrs. Spring. Strong shock waves and their use in the production and study of high temperature gases. High temperature chemical kinetics and its application to hypersonic external flows, rocket internal flows, and other phenomena of current interest. Chemical relaxation effects on flow fields and the method of characteristics including chemical reactions. Flame fronts and detonation waves. Experimental techniques. Mr. Resler.

7103. DYNAMICS OF RAREFIED GASES

Credit 3 hrs. Spring. Prerequisites, 7101, 7102. Flow regimes according to the Knudsen number. Theories of the shock structure at high Mach numbers. Boundary conditions at a solid wall. Slip-flow conditions. Free-molecule flows. Eigen function expansion of the linearized Boltzmann equation. Full-range and half-range moment methods. The model equation approach and recent developments for handling the transition regime. Mr. Shen.

7104. ADVANCED TOPICS IN HIGH TEMPERATURE GASDYNAMICS

Credit 3 hrs. Either term. Prerequisites, 7101, 7102. Current topics relating to present engineering practice and/or research interests of the faculty and staff.

7201. MAGNETOHYDRODYNAMICS I

Credit 3 hrs. Fall. Review of electromagnetic theory. Derivation of plasma conservation equations and an Ohm's law. Important parameters in magnetohydrodynamics and Alfvén waves. The pinch effect and hydromagnetic instabilities. Flow problems in magnetohydrodynamics. Hydromagnetic shock waves. Mr. Imai.

7202. MAGNETOHYDRODYNAMICS II

Credit 3 hrs. Spring. The three fluid model. Plasma oscillations. Tensor conductivity. The Saha equation, mean free paths, collision times. Diffusion and mobility, discharges. Excess electron temperature, collisionless effects. Mr. Imai.

7203. ADVANCED TOPICS IN MAGNETOHYDRODYNAMICS

Credit 3 hrs. Either term. Prerequisites, 7201, 7202. Current topics of interest in the field and/or related to the research interests of the staff and faculty.

7301. FLUID MECHANICS I

Credit 3 hrs. Fall. The continuum and the stress tensor. Vectors and tensors. Hydrostatics. Strain and rate-of-strain tensors. The ideal elastic continuum. Equilibrium and compatibility equations, boundary conditions. Plane stress and strain. The stress function. Elastic energy. Castigliano theorem and St. Venant's principle. The Newtonian fluid, viscosity and bulk viscosity Navier-Stokes equations. Poiseuille flow, Rayleigh and Stokes problems. The concept of the boundary layer. The ideal-fluid approximation. Kelvin and Helmholtz theorems. Irrotational flows. Mr. George.

7302. FLUID MECHANICS II

Credit 3 hrs. Spring. Laplace's equation. Source, sink, and doublet. Vortices. Biot-Savart theorem, the flow field of a vortex. Spherical and cylindrical harmonics. Methods of singularity distributions. Complex-variable methods. Wing theory. Acoustics. Compressible flows, subsonic and supersonic. Shock waves. Hypersonic flow. Rotational flows. Magnetohydrodynamics. Flow in the boundary layer, Prandtl theory. Heat transfer, separation. Mr. George.

7303. FLUID MECHANICS III

Credit 3 hrs. Fall. Prerequisites, 7301, 7302. Aerodynamics of compressible fluids. Brief review of linear theories. Improvements on linear theory: expansions in Mach number and thickness parameters; second order shock shapes; role of entropy in supersonic flows. Shock wave interactions. Exact theories: method of characteristics for rotational non-isentropic flows; hodograph transformation and limit lines, Kármán-Tsien and other model gases; conical flows. Transonic flow theory; similitude, flow in nozzles. Viscous and chemical effects in compressible flows; linearized non-equilibrium flow; shock wave structure; other topics of current interest. Mr. Seebass

7304. THEORY OF VISCOUS FLOWS

Credit 3 hrs. Fall. Prerequisites, 7301, 7302. Exact solutions of the Navier-Stokes equations. The small Reynolds number approximation. The boundary layer theory and the techniques for its solution. Compressibility effects. Stability of laminar flows. Turbulence. Mr. Shen.

7305. HYPERSONIC FLOW THEORY

Credit 3 hrs. Spring. Prerequisites, 7301, 7302. Hypersonic small disturbance theory and the related similitude; blast wave analogy; entropy layers. Newtonian theory and shock layer structure. Constant density solutions. The blunt body problem; numerical techniques. Viscous and real gas effects: ideal dissociating gas; viscous interactions; other real gas phenomena. Mr. Seebass.

7801. RESEARCH IN AEROSPACE ENGINEERING

(Credit to be arranged.) Prerequisite, admission to the Graduate School of Aerospace Engineering and approval of the Director. Independent research in a field of aerospace science. Such research must be under the guidance of a member of the staff and must be of a scientific character.

7901. AEROSPACE ENGINEERING COLLOQUIUM

Credit 1 hr. Prerequisite, admission to the Graduate School of Aerospace Engineering. Lectures by staff members, graduate students, personnel of Cornell Aeronautical Laboratory, and visiting scientists on topics of interest in aerospace science, especially in connection with new research.

7902. ADVANCED SEMINAR IN AEROSPACE ENGINEERING

Credit 2 hrs. Prerequisite, approval of the Director.

ENGINEERING PHYSICS

8051 and 8052. PROJECT

Terms 9 and 10. Credit 3 hrs. Fall and spring. Informal study under direction of a member of the University staff. The objective is to develop self-reliance and initiative, as well as to gain experience with methods of attack and with over-all planning, in the carrying out of a special problem related to the student's field of interest. The choice of a problem is to be made by the student in consultation with members of the staff.

8090. INFORMAL STUDY IN ENGINEERING PHYSICS

Fall or spring. Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the staff. Hours to be arranged.

8121–8122. CLASSICAL THERMODYNAMICS

Credit 3 hrs. Throughout the year. 3 Rec. Primarily for candidates for the degree of Bachelor of Engineering Physics. Introduction to classical thermodynamics, kinetic theory of gases, and statistical mechanics. Application to physical and engineering problems. Mr. Resler.

8252. SELECTED TOPICS IN PHYSICS OF ENGINEERING MATERIALS

Credit 1 hr. Fall term. Primarily for fifth year students in engineering physics; others with consent of instructor. Seminar-type discussion of special topics in the field of engineering materials, such as plastic and rheological properties; dielectric and magnetic behavior; semiconductors; radiation damage, etc. Emphasis is given to the interpretation of the phenomena in light of modern theories in physics of solids and liquids and their impact on the engineering applications. Current literature is included in the assignments. Staff.

8262. PHYSICS OF SOLID SURFACES

Credit 3 hrs. Spring. (Given in odd numbered years.) A lecture course for graduate students and upperclassmen. Permission of instuctor required. An introductory review of advances in theories of surface phenomena normally not covered in conventional courses in solid state physics or physical chemistry. Phenomena considered include thermodynamics of surfaces, atomic and molecular processes, electron emission effects, interfacial effects in solids and phase transformations at surfaces. Mr. Rhodin.

8301. INTRODUCTION TO ATOMIC AND NUCLEAR PHYSICS

Credit 3 hrs. Fall. This course will be replaced by Physics 436 which is included in the listing of courses under the Department of Physics. Selected topics in atomic, solid state, and nuclear physics; fundamental particles, atomic spectra, fundamentals of the quantum theory, the periodic table, X-rays, cosmic rays, properties of nuclei, and nuclear interactions. At the level of *Principles of Modern Physics* by French. See *Announcement of the College of Arts and Sciences*. Offered both terms. Fall: Mr. Clark; Spring: Mr. Woodward.

8302. NUCLEAR AND REACTOR PHYSICS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 8301 or Physics 314 or Physics 443. Nuclear particles, nuclear structure, properties of nuclei; radioactivity, applications of radioactivity; nuclear reactions; neutron reactions, nuclear fission. Neutron slowing down and diffusion; elementary reactor theory, types of reactors, reactor design criteria. At the level of *Nuclear Physics* by Kaplan and *Nuclear Reactor Engineering* by Glasstone. Mr. Fisher.

8309. LOW ENERGY NUCLEAR PHYSICS

Credit 3 hrs. Fall. 3 Lect. Prerequisites, a one-year introductory course in atomic and nuclear physics including quantum mechanics, such as 8301–8302 or preferably Physics 443–444; Math. 215–216 or equivalent. Primarily for graduate students in the field of nuclear science and engineering. Low energy nuclear physics as an organized body of experimental facts. Properties of ground and excited states of nuclei; models of nuclear structure; low energy nuclear reactions — scattering, absorption, fission, resonance effects, coherent scattering effects. At a level between *Introductory Nuclear Physics* by Halliday and *Nuclear Physics* by Fermi. Mr. Clark.

8312. REACTOR THEORY I

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 8309 and co-registration in Math. 416. The theory of neutron diffusion and slowing down is developed, and applied to basic integral experiments and to criticality calculations. Neutron transport theory is introduced and applied to some problems for heterogeneous reactors. At the level of *Reactor Analysis* by Meghreblian and Holmes. Mr. Cady.

8313. REACTOR THEORY II

Credit 3 hrs. Fall. 3 Lect. Continuation of 8312 primarily intended for students planning to do research in the fields of reactor physics and reactor engineering. Delayed neutron kinetics, fission product poisoning, non-linear kinetics, perturbation theory, temperature coefficients, control rod theory, hydrogenous reactors, neutron transport and heterogeneous reactor theory. At the level of *The Physical Theory of Neutron Chain Reactors* by Weinberg and Wigner. Mr. Cady.

8314. NEUTRON TRANSPORT THEORY

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 8312 or consent of instructor. The linear Boltzmann equation describing neutron migration in matter is intensively studied. Topics will vary, but may include Milne's problem, neutron thermalization, deep penetration of radiation, as well as a formal development of approximate methods of solution. At the level of *Neutron Transport Theory* by Davison. Offered in alternate years. Mr. Nelkin.

8333. NUCLEAR REACTOR ENGINEERING

Credit 3 hrs. Fall. 3 Lect. Prerequisite, consent of instructor. Primarily for second and third year graduate students. A selected set of topics representing the fundamentals of nuclear reactor engineering; energy conversion and power plant thermodynamics, fluid flow and heat transfer, thermal stresses, radiation protection and shielding, materials for nuclear reactors, economics of nuclear power and fuel cycles, instrumentation and control. At the level of *Nuclear Engineering* by Bonilla. Offered regularly in alternate years.

8334. NUCLEAR ENGINEERING SEMINAR

Credit 3 hrs. Spring. Prerequisite 8333. A group study of a reactor systems analysis or a reactor safeguards report. Emphasis on the interplay of requirements of safety and economics in the design of nuclear power systems. Offered in alternate years.

8342. READING COURSE IN RADIOCHEMISTRY

Credit 2 hrs. Spring. Primarily for graduate students. Reading assignments in the general field of radio-chemistry. Meetings for discussions at the convenience of the group, possibly for two hours every other week. Slanted toward the interests of the students, the course may include such topics as nuclear fission, radio-chemistry, nuclear concepts in geochemistry, neutron activation analysis, beta decay studies, radiation chemistry, hot-atom chemistry, biological effects of radiation, cosmic chemistry, nuclear reactions, neutrino searches, elemental abundances, tracer techniques, and applications in various fields. Mr. Fisher.

8351. NUCLEAR MEASUREMENTS LABORATORY

Credit 3 hrs. Spring. Two 2½ hour afternoon periods. Prerequisites, 8302 or 8309, or Physics 444. Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Some twenty different experiments are available in the fields of nuclear and reactor physics. Among these are experiments on emission and absorption of radiation; on radiation detectors and nuclear electronic circuits; on interactions of neutrons with matter (absorption, scattering, moderation, and diffusion); on activation analysis and radiochemistry; and on properties of a subcritical assembly. Many of the experiments use the TRIGA Reactor. The student is expected to perform eight to ten experiments, selected to meet his needs. Some stress is laid on independent work by the student. Mr. Clark and staff.

8352. REACTOR PHYSICS LABORATORY

Credit 3 hrs. Two 2½ hour afternoon periods. Prerequisites, 8351 and 8312. Laboratory experiments plus lectures on methods of reactor physics measurements. Experiments utilizing the Zero Power Reactor critical facility as well as the TRIGA Reactor are included. Mr. Clark and staff.

Other Courses

The following courses, described under other fields, may be of interest:

M.S. & E. 6872. NUCLEAR MATERIALS TECHNOLOGY

Credit 3 hrs. Spring.

Chem.E. 5760. NUCLEAR AND REACTOR ENGINEERING

Credit 2 hrs. Spring.

C.E. 2721. STRUCTURES IN NUCLEAR ENGINEERING

Credit 3 hrs. Spring.

INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

Service Courses

9101. INDUSTRIAL ORGANIZATION AND MANAGEMENT

Credit 3 hrs. Spring. 3 Lect. Management of an industrial enterprise; internal organization; effect of type of product, methods of manufacture, size of enterprise, and personnal involved; types of enterprises; plant location: centralization and decentralization trends; diversification and specialization; growth of industry.

9110. INTRODUCTION TO INDUSTRIAL ENGINEERING

Credit 3 hrs. Spring. 2 Rec., 1 Lab.-Comp. Prerequisite, 9170. An introduction to modern industrial engineering with emphasis on the design activities of industrial engineers in specifying workplace methods, the integration of many workplaces into integrated man-machine activity in such systems. Queuing theory, line balancing, and introductory concepts of linear programming will be presented as analytical methods to be used in the analysis of plant design problems. Laboratory work and computing problems will be drawn from situations of interest to chemical, mechanical, electrical, and civil engineers.

[9120. SYSTEMS ENGINEERING

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Elective for graduate students and qualified undergraduates not majoring in industrial engineering. Prerequisite, 9170. Methods of describing, analyzing, and manipulating complex, interrelated open systems. Graphical and mathematical analysis. Techniques of design of transportation, service, and information systems and appropriate evaluation methods. Not offered in 1965–66.]

9153. ENGINEERING ECONOMIC ANALYSIS

Credit 3 hrs. Spring. 3 Rec. An introduction to underlying economic principles and phenomena associated with engineering projects. Basic accounting and cost control principles and procedures will be presented initially as a frame of reference for a discussion of the more profound problems relating to the engineer's role as consultant on matters of investment and operations. In addition to the necessary accounting, topics will include cost concepts, profit-volume relationships and analysis, make-buy problems, minimum cost models, replacement and renewal models, etc.

9170. INTRODUCTORY ENGINEERING STATISTICS

Credit 3 hrs. Either term. 2 Rec., 1 Comp. Prerequisite, Mathematics 294 or equivalent. Applications of probability theory and statistics to industrial and engineering problems; point and confidence interval estimation; statistical testing of hypotheses; properties of binomial, Poisson, and hypergeometric distributions, and applications to sampling inspection problems; large sample theory and the normal distribution, small sample theory and Student's t and Chi-square distributions; introduction to correlation theory and curve fitting by least squares.

Required Courses

9301. INTRODUCTION TO INDUSTRIAL ENGINEERING

Credit 1 hr. Fall. 1 Lect. An introduction to industrial engineering with emphasis on the changing character of modern industrial engineering practice.

The work of the early industrial engineers will be studied and the impact of the developing science of operations on design methodology associated with the engineering of complex man-machine systems will be reviewed. The relationship of systems engineering, industrial engineering, administrative engineering, management engineering, operations engineering, operations analysis, operations research, and management science will be discussed. Typical problems of interest to present day industrial engineers and researchers will also be discussed to demonstrate the range of interest and application of industrial engineering methodology.

9302. MANUFACTURING PROBLEMS

Credit 2 hrs. Spring. 1 Lect. plus numerous plant visits. A course to give the student an awareness of the industrial environment with particular reference to processing situations and techniques; the realization of the physical meaning and magnitude of such problems as found in inventory, capacity, replacement, and maintenance to suggest a few problem areas. Engineering reports and writing will also be discussed with formal reports required based on the plant visits to be made.

9303. INDUSTRIAL ENGINEERING LABORATORY

Credit 4 hrs. Spring. 2 Lect., 2 Lab. Emphasis will be placed on the development of the scientific method as it relates to industrial engineering situations. Problem definition, development of hypotheses, and experimentation will be discussed with relevant techniques of measurement, estimation, design of experiments, prediction, and performance evaluation. An introduction to simulation techniques will also be included.

9310. INDUSTRIAL ENGINEERING ANALYSIS

Credit 4 hrs. Fall. 3 Lect., 1 Comp. Prerequisites, 9350 and 9370, or equivalent. The application of cost, probability, and statistical theories in the analysis and evaluation of data typical to industrial engineering and operations research. Topics to be included are process capability studies; various applications associated with control chart techniques; problems of sampling found in inspection and forecasting; applications and limitations of regression and correlation; probabilistic methods in inventory planning, life, and reliability studies; Monte Carlo simulation; and similar topics.

9311. INDUSTRIAL ENGINEERING DESIGN

Credit 4 hrs. Spring. 2 Lect., 2 Comp. Prerequisites, 9310, 9320. An introduction to engineering design with emphasis on applications in industrial engineering. All elements of the design process will be covered including problem definition, the determination of inputs and restraints, synthesis, analysis, and evaluation. Study will range from the design problems of the single workplace to the design of complex systems including manufacturing, transportation, and distribution facilities as typical systems problems.

9320. ANALYTICAL METHODS IN INDUSTRIAL ENGINEERING

Credit 4 hrs. Fall. 3 Lec.-Rec., 1 Comp. Prerequisite, 9350. Analytical techniques for the solution of design, planning, and operational problems. Linear programming and the simplex method; transportation problem and assignment problems as special cases: the dual and its interpretation: the quadratic assignment problem. Flows in networks and flow algorithms; application to the transportation problem. Practical application of these techniques to make-buy decisions, product mix problems, facility allocation, machine grouping, routing of materials handling equipment, raw material blending, and general operational planning problems. Introduction to the inventory problem.

9350. COST ACCOUNTING, ANALYSIS, AND CONTROL

Credit 4 hrs. Fall. 3 Lec.-Rec., 1 Comp. Accounting theory and procedures, financial reports; product costing in job order and process cost systems — historical and standard costs: cost characteristics and concepts for analysis, control, and decision making; differences between accounting and engineering objectives in the development and uses of cost data. Capital budgeting, investment planning, and introduction to decision making based on economic criteria.

9360. INTRODUCTION TO PROBABILITY THEORY WITH ENGINEERING APPLICATIONS

Credit 4 hrs. Fall. 3 Lec.-Rec., 1 Comp. Prerequisite, Math. 294 or equivalent. Definition of probability and basic rules of probability theory. Random variables, probability distributions, and expected values. Special distributions important in engineering work and relations among them; elementary limit theorems. Introduction to stochastic processes and Markov chains, and their applications in the construction of mathematical models of operation, with emphasis on queuing and inventory models.

9370. INTRODUCTION TO STATISTICAL THEORY WITH ENGINEERING APPLICATIONS

Credit 4 hrs. Spring. 3 Lec.-Rec., 1 Comp. Prerequisite, 9360. The application of statistical theory to problems associated with the analysis of data and inferences drawn therefrom. Principles of statistical inference: estimating the value of unknown parameters of probability distributions, testing hypotheses concerning these parameters; elements of statistical decision theory. Introduction to correlation theory and curve fitting by least squares. Applications in regression, statistical control, and experimentation.

9381. INTRODUCTION TO COMPUTER SCIENCE

Credit 3 hrs. Spring. 2 Lect., 1 Rec.-Comp. Required of industrial engineering majors. Introduction to the field of computer sciences including principles and characteristics of information processing equipment, programming languages, and applications. Topics are selected to illustrate a wide range of current and potential areas of application with emphasis being placed on the modern digital computer as a symbol manipulating device rather than as an arithmetic calculator. Number systems, computer logic and organization, and characteristics of current equipment are covered along with various aspects of programming. Also, introductory concepts and problems associated with using computers in information processing systems, real-time control systems, simulated experimentation, and the design process are also considered. Laboratory work involves use of the facilities at the Cornell Computing Center but this is not primarily a course in programming.

Graduate Honors Section of Undergraduate Courses

Registration in the following courses will be by permission of the instructor or department head only. Registrants generally will be limited to those industrial engineering undergraduates desiring an "honors" program or to graduate students taking a major, a minor, or an advanced professional degree in the Graduate Field of Industrial Engineering and Operations Research. Other qualified students will be admitted only if section sizes permit it.

9450. COST ACCOUNTING, ANALYSIS, AND CONTROL

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. This course covers the same topics as 9350 described above. The lecture sessions are held concurrently with 9350, but any recitation-computing sessions are independent and are reserved for graduate or honors undergraduates only.

9460. INTRODUCTION TO PROBABILITY THEORY WITH ENGINEERING APPLICATIONS

Credit 4 hrs. Fall. 3 Lec.-Rec. This course covers the same topics as 9360 described above, but all lectures are independent of 9360 lectures.

9470. INTRODUCTION TO STATISTICAL THEORY WITH ENGINEERING APPLICATIONS

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisites, 9360, 9460. This course covers the same topics as 9370 described above. The lectures are held concurrently with 9370. The recitation-computing session is independent of the 9370 recitations.

9481. INTRODUCTION TO COMPUTER SCIENCE

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. This course covers the same topics as 9381 described above. If 9381 is given concurrently, then two lectures would be common between the two courses and one lecture and the recitation-computing session for 9481 would always be independent. This course may also be given completely independent of 9381 in terms when 9381 is not being offered.

Elective and Graduate Courses

9501. ENGINEERING ADMINISTRATION

Credit 3 hrs. Spring. 3 Lec.-Rec. Prerequisite, graduate standing. Required of professional degree students, elective for others. Organization of the engineering function, planning and analysis of engineering activities. Project management and control. Problems of innovation and introducing technological change. Measurement and evaluation of engineering activities. Selected topics from current literature. Some use will be made of case studies.

[9502. PERSONNEL MANAGEMENT

Credit 3 hrs. Fall. 3 Rec. Intended for graduate students but open to qualified undergraduates. Prerequisite, 9170 or equivalent. Techniques of employee selection and evaluation, job evaluation, training, motivation; personnel department organization and interdepartmental relations. Not offered in 1965–66.]

[9510. WORK DESIGN AND MEASUREMENT

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Intended for graduate students but open to qualified undergraduates. Prerequisite, 9310 or permission. An advanced course in the analysis and design of man-micro systems and man-machine micro systems. Advanced statistical treatment of work measurement design, variables measurement, and work sampling; mathematical and statistical treatment of model design, standard data, control, and standards maintenance; study of the micro-systems design problem, including emphasis on the behavioral aspects and wage incentives. Not offered in 1965–66.]

9511. MANUFACTURING ENGINEERING

Credit 3 hrs. Fall. 1 Lect., 2 Rec.-Comp. Intended for graduates or qualified undergraduates. Prerequisite, 9310. The analysis and design of production facilities based on output requirements of the system. Attention will be directed towards the interaction of processing methods and requirements with handling methods and storage facilities. The effects of various levels of mechanization on operating costs and initial investment will be studied.

9512. STATISTICAL METHODS IN QUALITY AND RELIABILITY CONTROL

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 9170 or equivalent. A basic course primarily for undergraduates presented from an engineering standpoint. Contol concepts; control chart methods for attributes and for variables; process capability analysis; attributes acceptance sampling plans and procedures; double and multiple sampling inspection; elementary plans and procedures for variables; acceptance-rectification procedures; basic reliability concepts; exponential and normal distributions as models for reliability application; life and reliability analysis of components; analysis of series and parallel systems; stand-by and redundancy; elementary sampling-inspection procedures used for life and reliability.

9521. PRODUCTION PLANNING AND CONTROL

Credit 4 hrs. Spring. 3 Rec., 1 Comp. Required of professional degree graduate students but open to others and to qualified undergraduates. Prerequisite, 9170. Methods for the planning and control of large-scale operations with emphasis on manufacturing systems. Among the areas covered will be sales and production forecasting; manufacturing planning; routing; scheduling and loading; sequencing; dispatching; planning and control of inventories. Emphasis will be on mathematical and statistical methods for performing these functions; however, the empirical systems and procedures in common use will also be discussed and evaluated.

9522. OPERATIONS RESEARCH I

Credit 3 hrs. Spring. 3 Lec.-Rec. Prerequisites, 9360 or 9170, or permission of the instructor. Model design, methodology of operations research, linear programming, transportation problem, assignment problem, dual theorem, parametric linear programming, integer programming, non-linear programming, dynamic programming, introduction to inventory theory; comprehensive problems and case studies.

9523. OPERATIONS RESEARCH II

Credit 3 hrs. Fall. 3 Lec.-Rec. Prerequisites, 9370 or 9170, or permission of the instructor. Models for inventory and production control; replacement theory; queuing including standard birth and death process model and non-standard models, application of queuing theory; simulation; game theory, illustrative examples and problems. This course (and the preceding one) are not expected to provide an exhaustive treatment. Rather they will examine the broad range of OR type problems and the standard techniques used to handle them.

9524. PROBLEMS IN OPERATIONS RESEARCH

Credit 3 hrs. One 2-hr. meeting a week. Prerequisite, 9523 or equivalent. An advanced seminar concentrating on problem definition, measures of effectiveness, applicability of various analytical methods to the solution of real problems.

9525. FLOW AND SCHEDULING IN NETWORKS

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Elective for graduate students. Network analysis for continuous static flow; feasibility theorems, capacity determination, minimal cost operation. Sequencing models for deterministic discrete flow networks. Determination of capacity, routing and discipline for networks of queues.

9526. MATHEMATICAL MODELS—DEVELOPMENT AND APPLICATION

Credit 4 hrs. Fall. 3 Lec.-Rec., 1 Comp. Prerequisites, 9311 and 9320 or permission of the instructor. Required of professional degree graduate students, elective for others. This course will examine in some detail both probabilistic and deterministic models used in industrial engineering work. An examination and study of some of the standard models found in the literature will be made. Problems will be given in which the student will develop his own version of a proper model describing the situation. Emphasis will be placed on an understanding of the modeling process and the development of new models to meet specific conditions. First offered in 1965–66.

[9530. MATHEMATICAL PROGRAMMING

(Formerly 9520 in the '63 and '64 Announcements)
Credit 3 hrs. 3 Lec.-Rec. Prerequisite, permission of the instructor. Intended for graduate students. Theory, methods, computational techniques, and applications of mathematical programming. Classical constrained maximization and Lagrange multipliers. Linear programming; simplex method and variations; the dual and the dual simplex method; transportation programming. Integer programming. Quadratic and convex programming. Linear and quadratic assignment programming. Not offered in 1965–66.]

[9531. DYNAMIC PROGRAMMING

Credit 3 hrs. Spring. 3 Lec.-Rec. Prerequisite, permission of the instructor. Intended for graduate students. Topics discussed will be drawn from the recent technical literature. Emphasis will be placed on the analytical aspects of dynamic programming, although some computational questions will also be discussed. Not offered in 1965–66.]

9560. APPLIED STOCHASTIC PROCESSES

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Intended for graduate students but open to qualified undergraduates. Prerequisites, 9360 and 9370, or permission. An introduction to the theory of stochastic processes, with emphasis on applications to science and engineering. Topics drawn from sequences of random variables; Markov chains; renewal theory; applications to waiting time problems, to counter problems, and to reliability theory; birth and death processes; multiplicative processes; Gaussian processes; stationary processes; correlation and spectral distribution; applications to communication theory.

9561. QUEUING THEORY

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Intended primarily for graduate students. Prerequisites, 9360 and permission of the instructor. Definition of a queuing process. Explicit solutions of queuing problems when the arrival and service distributions are exponential or Erlang. A detailed study of the one-server problem for general distributions: the basic Wiener-Hopf equation; existence and uniqueness of stable solutions; approaches to solving the basic equation. Multi-server problems; bulk service; queues in series. Applications to specific engineering problems such as shop scheduling, equipment maintenance, and inventory control. Usually offered in odd numbered years.

9562. INVENTORY THEORY

Credit 3 hrs. Fall. 3 Lec.-Rec. Intended primarily for graduate students but open to qualified undergraduates. Prerequisites, 9360 and permission of the instructor. An introduction to the mathematical theory of inventory and production control with emphasis on the construction and solution of mathematical models; topics will be drawn from the recent technical literature and will include deterministic and stochastic demands; dynamic programming and stationary analyses of inventory problems; renewal theory applied to inventory problems; multi-echelon problems; statistical problems; and production smoothing. Usually offered in even numbered years.

9570. INTERMEDIATE ENGINEERING STATISTICS

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Intended for graduate students but open to qualified undergraduates. Prerequisite, 9170 or permission. Application of statistical methods to the efficient design, analysis, and interpretation of industrial and engineering experiments: rational choice of sample size for various statistical decision procedures and the operating characteristic curves of these procedures; curve fitting by least squares; simple, partial, and multiple-correlation analysis.

9571. DESIGN OF EXPERIMENTS

Credit 4 hrs. Fall. 2 Rec., 1 Comp. Intended for graduate students. Prerequisite, 9370 or 9570, or permission. Use and analysis of experimental designs such as randomized blocks and Latin squares; analysis of variance and covariance; factorial experiments; statistical problems associated with finding best operating conditions; response-surface analysis.

9572. STATISTICAL DECISION THEORY

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Intended for graduate students. Prerequisites, 9370 or 9570, or equivalent. The general problem of statistical decision theory and its applications. The comparison of decision rules; Bayes, admissible, and minimax decision rules. Problems involving a sequence of decisions over time, including sequential analysis. Use of the sample cumulative distribution function, and other nonparametric methods. Applications to problems in the areas of inventory control, sampling inspection, capital investment, and procurement.

9573. STATISTICAL MULTIPLE DECISION PROCEDURES

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Intended for graduate students. Prerequisite, 9571 or permission of the instructor. The study of multiple-decision problems in which a choice must be made among two or more courses of action. Statistical formulations of the problems. Fixed-sample size, two-stage, and sequential procedures. Special emphasis on applications to ranking problems involving choosing the "best" category where goodness is measured in terms of a particular parameter of interest. Recent developments.

9579. SELECTED TOPICS IN INDUSTRIAL STATISTICS

Credit 3 hrs. Either term. 2 Rec., 1 Comp. Intended for graduate students. Prerequisite, 9570 or permission. Selected topics chosen from such fields as nonparametric statistical methods, sequential analysis, multivariate analysis. Offered as required.

9580. DIGITAL SYSTEMS SIMULATION

Credit 4 hrs. Fall. 2 Rec., 1 Comp. Required of professional degree graduate students and open to others and qualified undergraduates. Prerequisites, 9381 and 9170, or permission of the instructor. The use of a program for a digital computer to simulate the operating characteristics of a complex system in time. Discussion of problems encountered in construction of a simulation program; synchronization and file maintenance, random number generation, random deviate sampling. Programming in the CLP and SIMSCRIPT languages. Problems in the design of effective investigations using simulation; statistical considerations when sampling from a simulated process. Applications of simulation to queuing, storage, traffic, and feedback systems. Applications will include use in the design of facilities, design of operating disciplines, and use in real time control of an operating system.

[9582. DATA PROCESSING SYSTEMS

Credit 4 hrs. Fall. 2 Rec., 1 Comp. Prerequisite, 9381 or permission. Concerned with design of integrated data processing systems for operational and financial control: questions of system organization, languages and equipment appropriate to this type of application, file structures, addressing and search problems, sorting techniques; problems of multiple-remote-input, on-line data processing systems; techniques of system requirement analysis. Not offered in 1965–66.]

9589. SEMINAR IN INFORMATION PROCESSING

Credit 3 hrs. Spring. One 2-hr. meeting per week. Offered as needed for majors in Industrial Engineering and Operations Research who have had at least two terms in courses related to the computer sciences. Topics will be drawn from such areas as simulation, heuristic programming, real-time control systems, tree-structured search techniques.

9590. SPECIAL INVESTIGATIONS IN INDUSTRIAL ENGINEERING

Credit and sessions as arranged. Either term. Elective for qualified undergraduate and graduate students. Offered to students individually or in small groups. Study, under direction, of special problems in the field of industrial engineering and administration. [Register only with the registration officer of the department.]

9591. INDUSTRIAL ENGINEERING AND ADMINISTRATION GRADUATE SEMINAR

Credit 1 hr. Both terms. A weekly $1\frac{1}{2}$ hr. meeting. For graduate students. Discussion and study of assigned topics of importance in the field.

9598. (FALL TERM), 9599 (SPRING TERM). PROJECT

Variable credit. A normal requirement of 6 credit hrs. must be completed by each candidate for a professional Master's degree, during the last two terms of matriculation. Project work requires the identification, analysis, and design of feasible solutions to some loosely structured industrial engineering problem. The solutions must be defended on sound engineering and economic arguments. The project work will normally be done independently although small groups will be allowed under special conditions. Formal and regular progress reports will be required and a final bound copy of each project report must be filed with the department as well as with the faculty advisers.

AGRICULTURAL ENGINEERING

(For a complete description of the courses in agriculture, see the *Announcement of the College of Agriculture.)*

151. INTRODUCTION TO AGRICULTURAL ENGINEERING

Credit 3 hrs. Spring. 1 Lect., 2 Lab. An introduction to the application of engineering principles to problems in agriculture, with a brief history of the development of agricultural engineering in the United States. Problems that are of primary interest to the agricultural engineer are used to provide understanding of the application of principles. Techniques for solution of these problems by modern digital computing methods will be introduced. Selected staff.

153. ENGINEERING DRAWING

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Designed to promote an understanding of the engineer's universal graphic language. The lectures will deal primarily with spatial relationships involving the problem-solving techniques of descriptive geometry. The laboratories will develop a working knowledge of drawing conventions, standard and advanced drafting techniques, and their application to machine, architectural, and pictorial drawing problems. Graphs and engineering graphics (nomography and graphical calculus) will also be included. Students will accomplish their work with drafting machines as well as the standard T-square and board. The first half hour of the laboratory will be utilized as an instruction-recitation period.

271. SURVEYING

Credit 2 hrs. Spring. 1 Lect., 1 Lab. A study of the principles and practices of surveying measurements. Fundamentals of measurement, sources of errors. Use of steel tape, engineer's level, transit, and plane table. Emphasis upon agricultural engineering application. Mr. Levine.

450. SPECIAL TOPICS IN AGRICULTURAL ENGINEERING

Credit 1 hr. Fall and spring. Open only to seniors. Presentation and discussion of the opportunities, qualifications, and responsibilities for positions of service in the various fields of agricultural engineering. Mr. French.

451–452. AGRICULTURAL ENGINEERING PROJECT

Total credit 6 hrs. Fifth year work in the form of projects. Individual work, or in small groups, with staff guidance. Primarily intended to develop initiative and self-reliance, as well as to provide for experience with engineering problems. Problems in the student's area of interest will be assigned after consultations between student and staff. Staff.

461. AGRICULTURAL MACHINERY DESIGN

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, Engineering 3321 or the equivalent. The principles of design and development of agricultural machines to meet functional requirements. Emphasis is given to stress analysis, selection of materials of construction, and testing procedures involved in machine development. Mr. Gunkel.

462. AGRICULTURAL POWER

Credit 3 hrs. Spring. 2 Lect., 1 Lab. and computing periods. Prerequisites, Engineering 3321, 3621, or the equivalent. Basic theory, analysis, and testing of internal combustion engines specifically for use in farm tractors, and other agricultural power applications. Tractor transmissions, Nebraska Tractor Tests, soil mechanics related to traction stability, shop dynamometers, fuels, hydraulic equipment. Mr. Siemens.

463. PROCESSING AND HANDLING SYSTEMS FOR AGRICULTURAL MATERIALS

Credit 4 hrs. Fall. 3 Lect., 1 Lab. Processes such as size reduction, separation, metering, drying, and refrigeration will be studied. Principles of and equipment for handling agricultural materials are included. Development of processing and handling systems and their electrical controls will be emphasized. Motors and electric power facilities are also included. Mr. Ludington.

471. SOIL AND WATER ENGINEERING

Credit 3 hrs. Spring. 3 Lect., 1 Lab. every other week. Prerequisites, Course 271, Engineering 2303, and Agronomy 200, or their equivalents. An advanced course in the application of engineering principles to the problems of soil and water control in agriculture. Includes design and construction of drainage systems and farm ponds; and design and operation of sprinkler systems for irrigation. Mr. Black.

481. AGRICULTURAL STRUCTURES

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisites, Engineering 2701 and 3621. Synthesis of complete farmstead production units, including structures, equipment, and management techniques. Integrated application of structural theory, thermodynamics, machine design, and methods engineering to satisfy biological and economic requirements. Mr. Scott.

491. LOW-COST ROADS

Credit 3 hrs. Primarily for foreign students. Offered upon sufficient demand, usually in fall term. Prerequisite, consent of instructor. Principally directed study with one $2\frac{1}{2}$-hour class session per week. Study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces. Mr. Spencer.

501. RESEARCH METHODOLOGY

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Selecting, planning, and conducting research including literature review, experimental design, collection and analysis of data, progress report writing, and budgeting. Use of dimensional analysis to develop general equations to define phenomena. Principles of similitude with reference to both agriculture and engineering. Mr. Gunkel.

601. GENERAL SEMINAR

1 hr. per week. Fall and Spring. Required of graduate students. Presentation and discussion of research and special problems in agricultural engineering. Staff.

602. TECHNICAL SEMINAR

Credit 1 or 2 hrs. Spring. Thorough investigation and discussion of research in a special area of interest to those enrolled. Staff.

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